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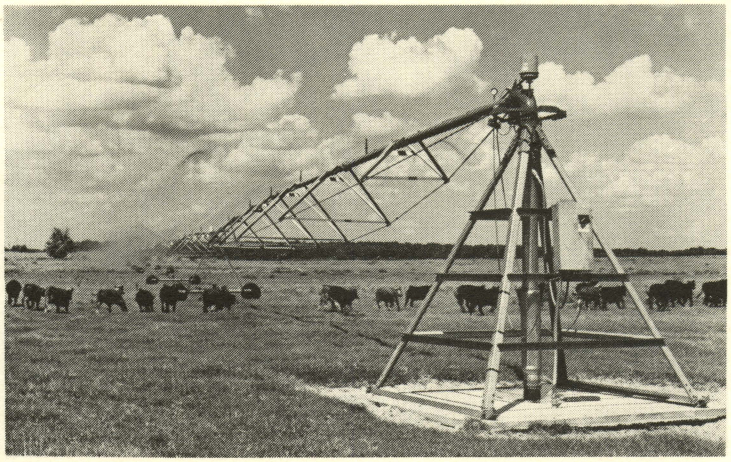

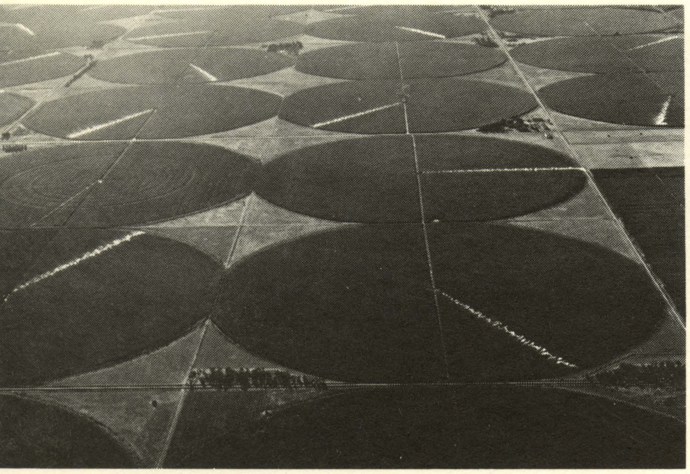

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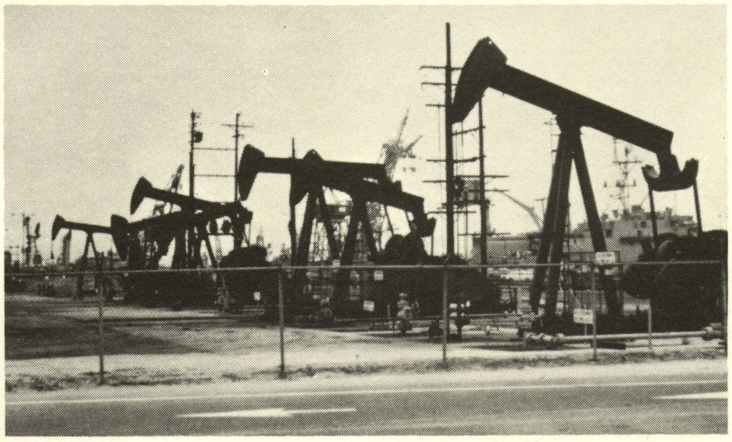

AGRICULTURAL AND RURAL DEVELOPMENT

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U.S. AGRICULTURAL PRODUCTION UNDER LIMITED ENERGY SUPPLIES, HIGH ENERGY PRICES, AND EXPANDING AGRICULTURAL EXPORTS

By

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and

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This research study was completed under a grant from the RANN Program (Research Applied to National Needs) of the National Science Foundation (GI-32990). Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the view of NSF.

CARD Report 69

The Center for Agricultural and Rural Development

Iowa State University

Ames, Iowa 50011

November 1976

PREFACE

Food and energy are commodities essential for human existence. Even aside from the energy problem that has recently emerged, the world food problem has been intensifying. The United States is an important source for meeting world food needs. Because modern farming has become so dependent on energy from fossil fuel, some agricultural specialists indicate that the role of the United States in helping feed the world is greatly dependent on world energy developments. A severe energy shortage, brought about by either world political conditions or rapid exhaustion of petroleum supplies, could greatly limit the ability of the United States to produce food and could force agriculture to turn to practices other than those currently used. Also, it could have great interregional impacts on income distribution and production patterns.

This study evaluates changes that might come about in U.S. agriculture under energy shortages expressed in prices and supplies for energy. It analyzes shifts in production among regions and between irrigated and dryland agriculture if energy were limited in farming or if prices rose to higher levels. It also examines changes that could come about in cropping technology and crop mixes under these conditions. It evaluates changes in resource values and related quantitites. Finally, it examines a pattern of agriculture consistent with minimizing the energy requirements of agriculture.

The study includes the major field crops produced in the United States. Livestock production is handled on an exogenous basis and does not adjust to the various energy situations. Thus, the study could be considered the first one of a series. Later studies may incorporate livestock and food processing industries.

The energy units used in this report are somewhat arbitrarily chosen. However, we feel that these units are most meaningful for a wide range of readers. These units are often used in similar publications. For readers who prefer a different set of units, conversion tables have been provided at the end of the text (Tables F.1 and F.2).

This research was made possible by a grant from the National Science Foundation (NSF), Research Applied to National Needs (RANN) program. Many people at the Center for Agricultural and Rural Development helped in accomplishing this work. Ken Nicol provided input both in constructing the model and in interpreting the results. Nancy Turner, Steve Griffin, Francis Epplin, and Hiren Sarkar had major responsibility for computer programming, data collection, and tabulating the results. Vince Sposito assisted with the solution phase of the model. Some thanks are also due to all the persons who reviewed earlier drafts of this publication and provided us with valuable suggestions.

The Authors

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I. SUMMARY

This study analyzes the potential long-run behavior of U.S. agricultural production under various energy alternatives. The study concentrates on four basic issues: (a) minimization of the total energy use in crop production, (b) agricultural production subject to an energy shortage, (c) agricultural production under high energy prices, and (d) high agricultural exports accompanied by high energy prices. Other policies (e.g., restriction on regional energy use, reduction in the supply of a specific energy source, etc.) also could be examined. However, the alternatives examined cover some of the most fundamental issues that U.S. agriculture is likely to face in the near future. The analysis investigates resource use and prices, crop location and utilization, food costs, commodity prices, farming methods, and environmental impacts.

The Model

The interregional model is a reduced version of the linear programming model developed at the Center for Agricultural and Rural Development for the "1975 National Water Assessment" [29]. Five different alternatives (models) are evaluated. These are: a base run (Model A), energy minimization (Model B), 10 percent energy cut (Model C), high energy prices (Model D), and high exports accompanied by high energy prices (Model E).

Four of these alternatives, Models A, C, D, and E, minimize the total cost of crop production and transportation. These models suppose

a competitive equilibrium wherein all agricultural resources receive their market rate of return. Land return, however, is determined endogenously by the model. One alternative, Model B, minimizes the total amount of fossil fuel energy (in KCAL)[1] consumed in crop production and transportation. The minimization procedure is subject to a set of linear restraints corresponding to the availability of land, water, fertilizer, and energy supplies by regions, production requirements by location, the nature of crop production, and a final set controlling domestic and foreign demands through commodity supply-demand equilibrating restraints. There are 880 restraints in the model.

Activities in the model simulate crop rotations, water transfer and distribution, commodity transportation, chemical nitrogen supplies, manure nitrogen supplies, and energy supplies. There are 10,700 activities in the model. Endogenous crop activities are corn grain, sorghum grain, corn silage, wheat, soybeans, cotton, sugar beets, oats, barley, legume and nonlegume hay. The projected production and regional distribution of all other crops and livestock are exogenously determined.

All alternatives assume a U.S. population of 232.2 million by 1985. All results refer to 1985. Models A, B, C, and D assume agricultural exports at 1985 OBERS E' levels [49];[2] and Model E assumes exports at 1985 OBERS E' high levels. Because of the identical export levels and the minimization nature of the study, the production levels for the first

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[1]One KCAL = 1,000 calories. One calorie is the heat required to raise the temperature of one cubic centimeter of water one degree Celsius.

[2]OBERS projections of economic activity in the United States are made by the U.S. Water Resources Council, an independent Executive agency of the U.S. Government. The OBERS E' exports see Table 3.5.

four alternatives are the same (Table 1.1). They differ, however, from the high export alternative. Cost of production, transportation, and other inputs are in terms of 1972 prices. However, for energy adjustments have been made to reflect the relative price changes of energy to other imputs between 1972 and 1974.[1]

Table 1.1. Crop production in 1975, under "normal" export (Models A, B, C, D) and high exports (Model E) in 1985.

Crop	Unit	1975	Model A,B,C,D	Model E
			1,000 Units	
Corn grain	bushels	5,809,637	5,800,197	6,598,797
Sorghum grain	bushels	758,454	1,043,516	1,375,269
Barley	bushels	382,980	1,045,602	1,124,363
Oats	bushels	656,862	952,847	1,013,885
Wheat	bushels	2,133,803	1,709,475	2,306,715
Soybeans	bushels	1,521,370	1,613,103	2,565,568
Hay	tons	132,917	342,775	373,743
Silage	tons	120,595	125,709	74,113
Cotton	bales	8,327	10,911	11.015
Sugar beets	tons	29,270	33,583	33,583

Source: Statistical Reporting Service [42].

The base run (Model A) is the control alternative used for comparison with the other alternatives. The base run represents the normal long run adjustment of agricultural production if energy prices do not increase above 1974 levels, no restrictions are imposed on the amount of energy used in agricultural production and exports remain "normal." Energy minimization (Model B) represents the maximum possible achievement of energy savings

[1]Between 1972 and 1974 the index of prices paid by farmers increased by less than 40 percent while fuel prices more than double[41].

subject to the technology defined in the study. It minimizes the total energy (KCAL) required for field operations, irrigation, fertilizers, drying, transportation, and pesticides regardless of how high the cost of food might be. A somewhat similar situation, but one which minimizes the cost of food and fibers, is analyzed under the 10 percent energy cut alternative (Model C). Under this alternative, the amount of energy (KCAL) available to agricultural production is restricted to only 90 percent of the base run. The very likely situation of much higher energy prices in the future is examined in Model D. With the high energy price alternative (Model D), the cost per KCAL is assumed to double relative to the base run. The high export alternative (Model E) retains high energy prices and also assumes exports of agricultural products to increase substantially from the base run by 1985.

Prior to review of the results, the relationships between basic assumptions made in the study and the results should be noted. The most important assumption is the fixed energy coefficients for crop production. Under this assumption, the energy required to produce a given unit of output can be changed only in line with known production methods incorporated in the study. This assumption implies no energy waste in agricultural production. Furthermore, it implies no direct improved energy efficiency in agriculture except for those improvements due to reduced tillage, less irrigation, smaller fertilizer applications, and other methods explained in the text. Undoubtedly, improved technology and reduced energy waste would lessen the impact of the energy crisis on agricultural production and on the nation's well being.

The Energy Crisis, Commodity Prices, and Food Costs

The results of the study clearly demonstrate the great difference between an energy reduction policy and a high energy price policy. Even a 10 percent energy reduction for agricultural production leads to a sharp increase in programmed commodity prices. However, doubling energy prices results in a much smaller relative increase in programmed commodity prices.[1] This phenomenon is explained by a very low demand elasticity for energy in agricultural production. For example, doubling energy prices leads to only a 5 percent reduction in the total energy use in agriculture. The derived energy demand curve in agricultural production becomes more inelastic as energy use declines. Hence, additional energy reductions can be achieved only by successively larger increases in commodity prices (Figure 1.1). For example, the first 5 percent reduction in energy use (from 100 to 95 percent) results in about a 13 percent increase in commodity prices. Another 5 percent reduction (from 95 to 90 percent) results in an additional 42 percent increase in commodity prices. An additional 5 percent reduction (from 90 to 85 percent) results in such a large increase in commodity prices that it would seem unlikely to be acceptable even under the most severe energy shortage.

Possible increases in food retail costs can not be obtained directly from the above results. However, most of the marketing processes such

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[1] We use the term programmed prices to indicate that the prices are weighted shadow prices determined in the model. Hence, for purposes of the study, they are normative supply prices. They are not market equilibrium prices.

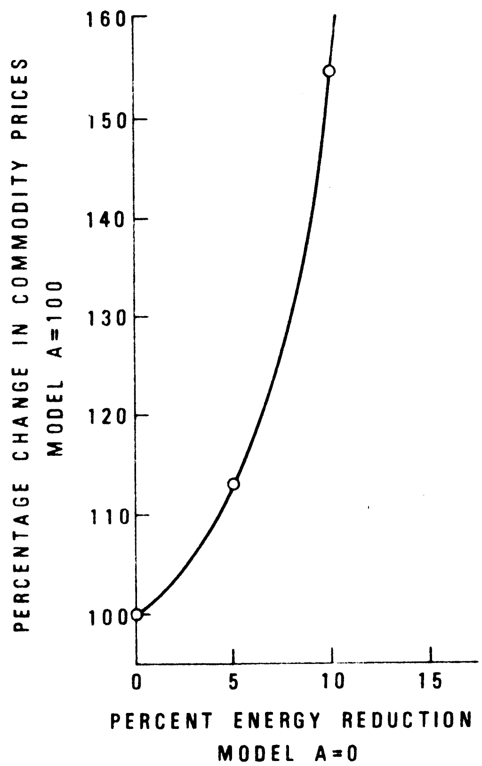

Figure 1.1. Effect of energy reduction on percentage change in programmed commodity prices.

as transportation, freezing, canning, etc., are much more energy intensive than onfarm production [16]. If restrictions under an energy crisis were not limited to onfarm production but also were applied to food processing and transportation, increases in food cost would be larger than indicated above for farm products only. But, this is true only if we use parallel assumptions of no energy waste and no substantial energy efficiency improvements in processing and marketing of farm products.

Resource Use In Agricultural Production

Changes in energy supplies and prices have major impacts on resource use in agriculture and their costs. The most important energy-saving "strategy" that occurs in the model is reduction in energy use for irrigation and commercial nitrogen purchase (Table 1.2). The 10 percent energy reduction (Model C) is accompanied by a 41 percent reduction in irrigated acres. Even the 5 percent energy reduction that results from doubling energy prices (Model D) leads to a 22 percent reduction in irrigated acres. This situation could be substantially different if U.S. agriculture were to face high export demands. Under high exports, irrigated acres increase 12 percent above the base run even when energy prices are twice their 1974 levels.

The amount of nitrogen used varies only slightly in the first four alternatives (Table 1.2). Although a reduction occurs in per acre application of nitrogen, it is accompanied by a larger crop acreage. Accordingly, the net result is only a small reduction in overall nitrogen use. Commercial nitrogen purchased, however, declines sharply under both the energy minimization and the 10 percent energy reduction alternative. Thus, as expected, the energy cirsis increases the utilization of manure and legume crops as alternate sources of nitrogen. It would also substantially increase nitrogen prices[1].

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[1]The nitrogen prices, as well as all other prices included in Table 1.2, are weighted shadow prices or imputed value per unit of the three resources.

Table 1.2. Land use, water use, nitrogen use, changes from the base run (Model A) and resource prices in 1985, United States averages

Item	Unit	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
				1,000 Units		
Dryland used	acres	320,707	347,453	338,181	329,026	341,988
Irr. land used	"	22,894	9,622	13,495	17,905	25,615
Total land used	"	343,601	357,075	351,676	346,931	367,603
Slack land	"	25,965	12,490	17,889	22,634	1,962
Water used	acre-feet	47,421	22,598	30,377	36,890	51,389
Nitrogen used	tons	6,743	6,438	6,470	6,520	10,554
Nitrogen purchased	"	2,126	1,396	1,569	1,829	5,573
				Changes from Model A		
Dryland used	percent	100.00	108.34	105.44	102.59	106.63
Irri. land used	"	100.00	42.03	58.95	78.21	111.88
Total land used	"	100.00	103.92	102.35	100.97	106.98
Slack land	"	100.00	48.10	68.90	87.17	7.56
Water used	"	100.00	47.65	64.06	77.79	108.37
Nitrogen used	"	100.00	95.48	95.95	96.69	156.52
Nitrogen purchased	"	100.00	65.66	73.80	86.03	262.14
				Resource Prices		
Average land rent	$/acre	16.78	N.A.	31.88	20.00	101.58
Average water price	$/acre-foot	9.29	N.A.	10.59	9.70	12.75
Nitrogen price	¢/lb.	12.14	N.A.	36.94	18.21	19.47

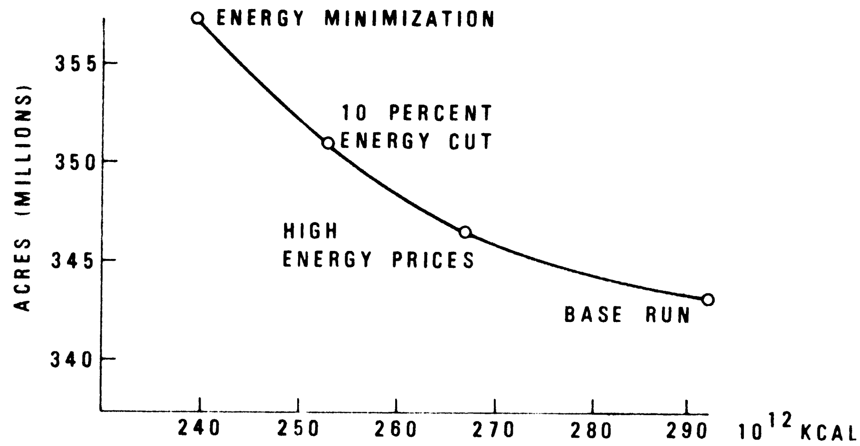

Figure 1.2. Energy-cropland substitution among different alternatives.

Under high exports (Model E), the total amount of nitrogen use increases sharply. This occurs as unused cropland (i.e., land not in crops) is rapidly exhausted and additional production needed to meet the higher exports can only be obtained by higher yields through greater fertilizer application. Under high exports the increase in commercial nitrogen purchased is much greater than the overall increase in nitrogen use (Table 1.2).

In all the alternatives analyzed, cropland currently not in crop production is substituted for other resources, water, fertilizers, and especially energy (Figure 1.2). An important part of the changes, however, involves converting irrigated land to dryland crops. For example, under the 10 percent energy reduction (Model C) irrigated crops decline by 9.4 million acres while dryland crops increase by 17.5 million acres (Table 1.2). Undoubtedly, such changes would have great impacts on irrigated farming and rural communities in the western states.

The rate of resources utilized (described above) is clearly related to the value of resources in terms of shadow prices (supply prices, Table 1.2). Substantial increases in land rents take place both under the 10 percent energy cut (up to 90 percent) and under the high exports (up by more than 605 percent). Water prices vary only slightly under both the 10 percent energy cut and high energy price alternatives as production is moved away from irrigated cropland toward dryland crops. The sharp increase in nitrogen price under the 10 percent energy cut (Table 1.2) is entirely because of the increase in direct energy costs.

Among the most important results of this study are the energy shadow prices (Table 1.3) derived under the 10 percent energy cut alternative (Model C). The price of 1,000 KCAL more than quadruples from .858 cents in the base run (Model A) to 3.505 cents per 1000 KCAL (Model C). Energy shadow prices would be substantially higher if such an energy shortage took place under high exports. This is true because agricultural production requires 29 percent more energy under the high export alternative than under the base run (Table 1.3).

The distribution of energy use in agricultural production among the different input categories is shown in Table 1.4. Tractors, combines, and other self-propelled farm machinery consume about two-thirds of all the energy in agricultural production. The amount of energy required for fertilizers varies according to the energy and export alternatives. Under energy minimization (Model B), energy use for nitrogen fertilizers declines sharply as chemical nitrogen application is reduced and more nitrogen is replaced by manure and

Table 1.3. Energy sources use, changes from the base run (Model A), and prices under different alternatives in 1985, United States averages

Fuel Source	Unit	Base Run (Model A)[a]	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
				Energy Use		
Diesel	million gallon	5,377	5,179	5,340	5,407	5,964
Nat. gas	million ft.^{3}	180,060	111,198	124,332	152,966	400,458
LPG	million gallon	657	534	571	625	740
Electricity	million KWH	12,014	5,738	7,607	8,915	13,025
Total KCAL	10^{12}	292.438	249.622	263.194	277.354	377.544
				Changes from Model A		
Diesel	A = 100	100.00	96.32	99.31	100.56	110.92
Nat. gas	"	100.00	61.76	69.05	84.95	222.40
LPG	"	100.00	81.28	86.91	95.13	112.63
Electricity	"	100.00	47.76	63.32	74.21	108.42
Total 1000 KCAL	"	100.00	85.36	90.00	94.84	129.10
				Energy Prices		
Diesel	¢/gallon	35.614	N.A.	136.829	68.267	77.858
Nat. gas	¢/1000 ft^3	62.554	N.A.	240.333	119.906	136.753
LPG	¢/gallon	30.008	N.A.	115.291	57.521	65.602
Electricity	¢/KWH	2.387	N.A.	9.171	4.576	5.218
Total 1000 KCAL	¢/1000 KCAL	.858	N.A.	3.505	1.716	1.716

[a]Energy prices are based on 1974 prices.

legume crops. However, high exports (Model E) require about 262 percent more energy for nitrogen fertilizers than does the base run (Model A).

Irrigation contributes 58 percent, 66 percent, and 68 percent of the total energy reduction achieved under energy minimization, 10 percent energy cut, and high energy price alternatives, respectively. Commercial nitrogen, however, is responsible for only 34 percent, 32 percent, and 30 percent of the energy reductions under the same three alternatives. All other input categories are responsible for only minor reductions in energy use. The amount of energy use by these inputs under the different energy alternatives (Table 1.4) might actually be greater than the energy use by these inputs in the base run (Model A).

Clearly, proportional reduction in energy use by all input categories is by no means the least-cost option. As a matter of fact, to achieve the least-cost energy saving option, some input categories must use more energy than previously represented by these inputs. For example, under energy minimization (Model B), energy use for irrigation declines by 41.020×10^{12} KCAL from the base run. But at the same time, energy use for transportation of raw agricultural products increases by 26.124×10^{12} KCAL from the base run (Model A). Furthermore, the reduction in fuel use for field operations, due to a much larger proportion of reduced tillage acreages under energy minimization (88 percent), requires a 28 percent increase in the energy use for pesticides. These examples demonstrate why a piecemeal approach to energy saving is undesirable. The possibility of input substitution as well as the

Table 1.4. Energy use in crop production and percent distribution for different alternatives in 1985, United States totals

Inputs	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			10^{12} KCAL		
Fuel for machinery	169.573	164.956	169.435	171.520	184.465
Pesticides	7.374	9.405	7.896	7.518	7.875
Nitrogen fertilizers[a]	36.455	11.969	26.904	31.363	95.563
Nonnitrogen fertilizers	7.207	7.287	7.036	7.060	8.019
Crop drying	13.056	12.148	12.610	12.933	14.320
Irrigation	41.456	.416	21.737	29.849	44.862
Transportation	17.317	43.441	17.576	17.110	22.440
Total	292.438	249.622	263.194	277.353	373.544
			Percent Distribution		
Fuel for machinery	57.99	66.07	64.38	61.84	48.86
Pesticides	2.52	3.77	3.00	2.71	2.09
Nitrogen fertilizers	12.47	4.79	10.22	11.31	25.31
Nonnitrogen fertilizers	2.46	2.92	2.67	2.55	2.12
Crop drying	4.46	4.87	4.79	4.66	3.79
Irrigation	14.18	.17	8.26	10.76	11.89
Transportation	5.92	17.41	6.68	6.17	5.94
Total	100.00	100.00	100.00	100.00	100.00

[a]Energy for nitrogen fertilizers indicates energy for commercialy purchased nitrogen fertilizers only.

increased use of all other inputs might actually result in no energy savings. Thus, an energy saving program in agriculture and elsewhere should give special attention to input substitution within the industry and to the possible increased use of inputs by other industries as demonstrated by an increase in transportation under the energy minimization alternative.

Crop Acreages

The different energy and export policies analyzed in the study have great impacts on crop acreages (Table 1.5). In general, under an energy cut and high energy prices, dryland crop acres increase and irrigated acres decrease. For some crops the reduction in irrigated acres under the energy reduction alternative is especially severe. Crops that lose more than half their irrigated acres under a 10 percent energy cut are corn (down 63 percent), wheat (down 81 percent), and soybeans (down 88 percent). Even under high exports accompanied by high energy prices (Model E) irrigated acreages of soybeans, hay, and cotton are smaller than in the base run alternative (Model A). A very surprising result is the sharp increase in irrigated corn grain (from 2.1 to 5.5 million acres) because of to the high exports. In part, this increase is explained by the additional production required to meet the larger export demands that cannot be obtained from the now exhausted dryland.

Table 1.5. Crop acreages and changes from the base run in 1985, United States totals

Crop	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			1,000 Acres		
Corn dryland	60,764	65,174	63,833	62,288	60,063
irrigated	2,120	780	792	1,729	5,476
Sorghum dryland	18,482	19,990	19,749	18,685	19,152
irrigated	1,682	617	927	1,703	3,692
Wheat dryland	52,234	54,695	56,023	53,392	67,589
irrigated	2,161	617	405	1,493	2,814
Soybeans dryland	77,596	78,114	77,472	77,683	77,069
Soybeans irrigated	1,781	115	219	219	511
Hay dryland	56,982	63,307	59,878	59,712	65,249
irrigated	8,213	3,919	5,700	6,074	7,160
Cotton dryland	7,148	9,636	8,088	7,576	7,574
irrigated	2,066	986	1,367	1,810	1,825
			Changes from Model A		
Corn dryland	100.00	107.26	105.05	102.51	98.85
irrigated	100.00	36.79	37.36	81.56	258.30
Sorghum dryland	100.00	108.16	106.85	101.10	103.63
irrigated	100.00	36.68	55.11	101.25	219.50
Wheat dryland	100.00	104.71	107.25	102.22	129.40
irrigated	100.00	28.55	18.74	69.09	130.22
Soybeans dryland	100.00	100.67	99.84	100.11	99.32
irrigated	100.00	6.45	12.30	12.30	28.69
Hay dryland	100.00	111.10	105.08	104.79	114.51
irrigated	100.00	47.72	69.40	73.96	87.18
Cotton dryland	100.00	134.81	113.15	105.99	105.96
irrigated	100.00	47.73	66.17	87.60	88.33

Regional Impacts

The energy alternatives have severe impacts on the regional distribution of crop production. The main factors responsible for the regional shifts are changes in the size and the location of irrigated farming. In order to facilitate the presentation of the results, the United States is divided into seven major zones (Figure 1.3). These zones are formed by aggregating adjacent market regions.

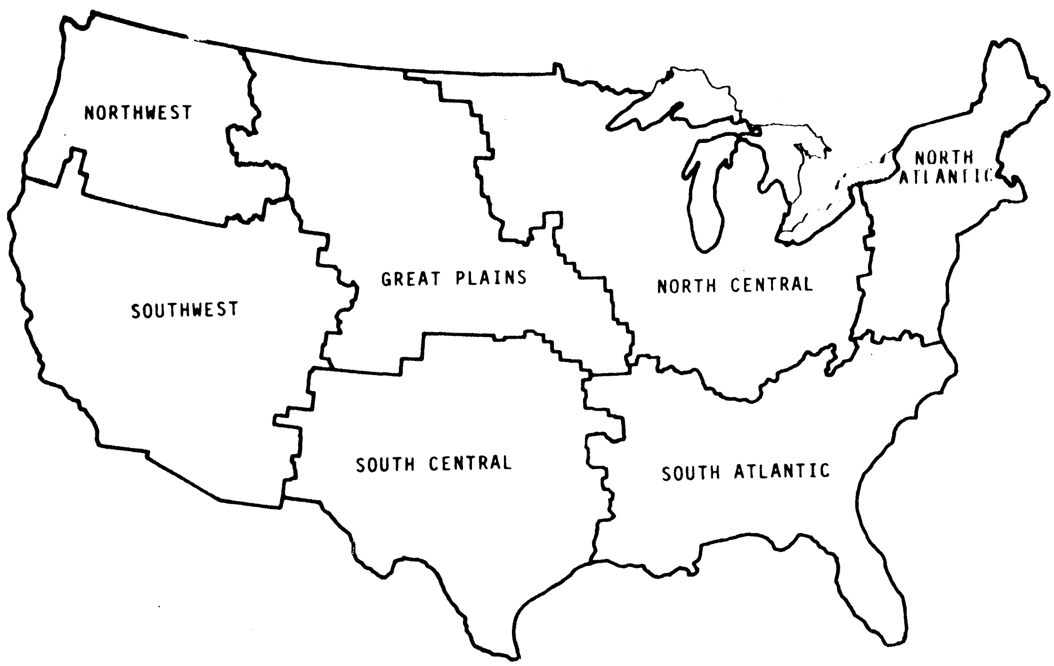

Figure 1.3. The seven major zones

Only very small changes in dry cropland take place in the eastern regions (Table 1.6). For the western regions, however, changes in dry cropland use are substantial. The increase of dryland used in western regions is much greater than the reduction in irrigated cropland use. This occurs because more than one acre of dry cropland must

Table 1.6. Regional distribution of dry and irrigated endogenous cropland for different alternatives in 1985 [a]

	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			Dryland 1,000 acres		
North Atlantic	11,420	11,373	11,382	11,431	11,473
South Atlantic	40,790	41,359	40,789	40,788	43,640
North Central	135,470	138,239	137,342	135,157	141,311
South Central	47,902	55,282	52,574	48,869	55,244
Great Plains	67,736	72,126	70,935	71,013	69,600
Northwest	7,525	13,960	12,718	11,962	12,634
Southwest	2,090	6,017	3,484	2,154	3,546
United States	312,931	338,352	329,221	321,372	337,446
			Irrigated Land 1,000 acres		
North Atlantic	N.A.	N.A.	N.A.	N.A.	N.A.
South Atlantic	N.A.	N.A.	N.A.	N.A.	N.A.
North Central	138	0	138	138	138
South Central	5,665	1,098	1,928	4,849	7,166
Great Plains	6,331	3,850	5,314	5,326	8,502
Northwest	4,152	398	448	1,123	2,520
Southwest	6,608	4,276	5,668	6,469	7,290
United States	22,894	9,622	13,495	17,905	25,615

[a]Dry cropland does not include summer fallow.

be substituted for every irrigated acre taken out of production in order to maintain previous production levels. The high export alternative (Model E) especially benefits the North Central, South Central, and the Great Plains as both dry and irrigated cropland increased substantially compared with the base run (Model A).

The severe impacts of an energy shortage and high energy prices on irrigation are also shown in Table 1.6. Under the 10 percent energy cut and high energy prices, irrigated cropland declines substantially in the South Central, Great Plains, Northwest, and the Southwest.

Regional changes in irrigated cropland can be compared in Figures 1.4 and 1.5. Changes under the 10 percent energy cut (Model C, Figure 1.5) are somewhat less severe than those under energy minimization. The large reduction in irrigated cropland in the South Central region (Texas, Oklahoma, and Kansas) is mainly because of ground water depth as well as the great proportion of ground water in the total water supply to agriculture. In the South Central region where a pumping depth of 1,000 feet is common [12], irrigated crops use four to five times more energy than do dryland crops. Irrigated farming in the Northwest region (Washington, Oregon, and Idaho) is also greatly effected by the energy reduction. In contrast with the South Central region, the high energy intensity of irrigation in the Northwest region is mainly due to surface water pumping, much of which is pumped from the Columbia River [12]. Electricity, the nation's most expensive energy source, is widely used in the Northwest.[1] Thus, when

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[1] In the Northwest, hydroelectric plants supply most of the electricity needs. But, at least some of that electricity can be transferred to nearby regions which use fossil fuel to generate electricity.

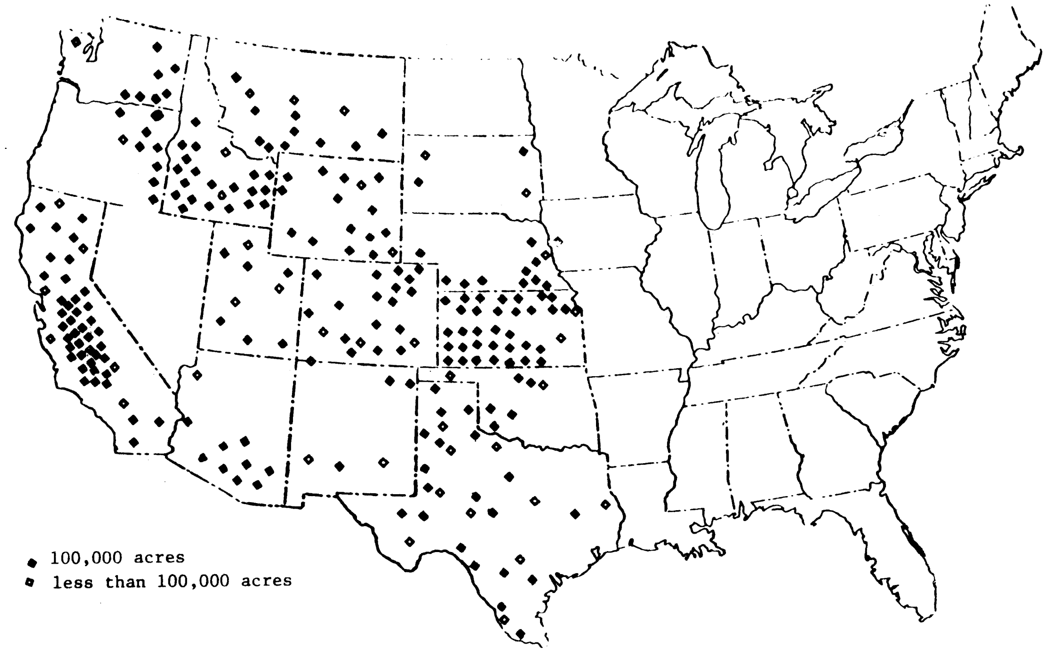

Figure 1.4. Location of endogenous irrigated cropland under the base run (Model A) in 1985

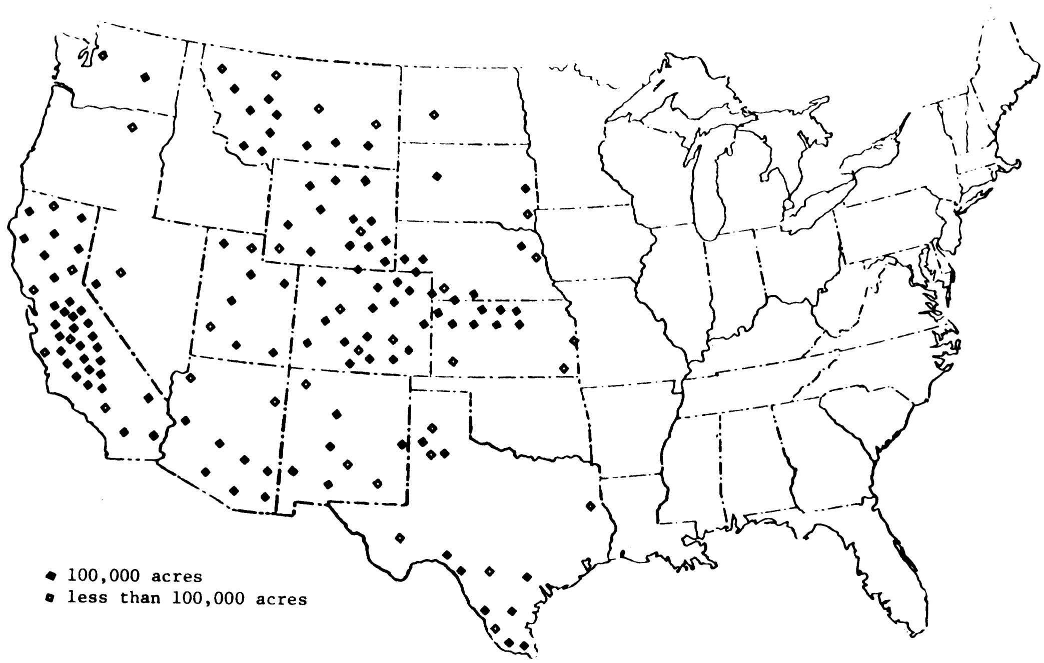

Figure 1.5. Location of endogenous irrigated cropland under 10 percent energy reduction (Model C) in 1985

charged at ongoing rates the competitiveness of irrigated crops is further reduced in that region. For example, irrigated corn in the Northwest region uses 1,247 KWH of electricity per acre for irrigation alone. At 1974 prices that electricity adds $28.50 per acre to other production costs.

Regional and National Farm Income

Important changes also take place in farm income. Total return[1] to land, water, and labor increases by 57 percent under the 10 percent energy cut, 15 percent under high energy prices, and 460 percent under the high exports, as compared to the base run. Whether farmers are actually better off under an energy shortage or high energy prices basically depends on what happens to the cost of farm inputs as well as on their ability to pass the additional costs to consumers. Energy shortages as well as high energy prices have a great impact on the regional farm income distribution (Figure 1.6). The four western regions (South Central, Great Plains, Northwest, and Southwest) lose in relative income shares under both the energy cut and high energy prices. However, under the high export alternative these regions increase their relative income share while the eastern regions (North Atlantic, South Atlantic, and the North Central) reduce their relative income share. Clearly the regional income distribution is related to

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[1]Total return to resources is the amount of the resources used times their respective supply prices (shadow prices).

the proportion of irrigated farming relative to dryland farming in each region. Thus a shift from irrigated crops to dryland crops due to an energy crisis also leads to a shift in the relative income share in favor of the dryland farming regions.

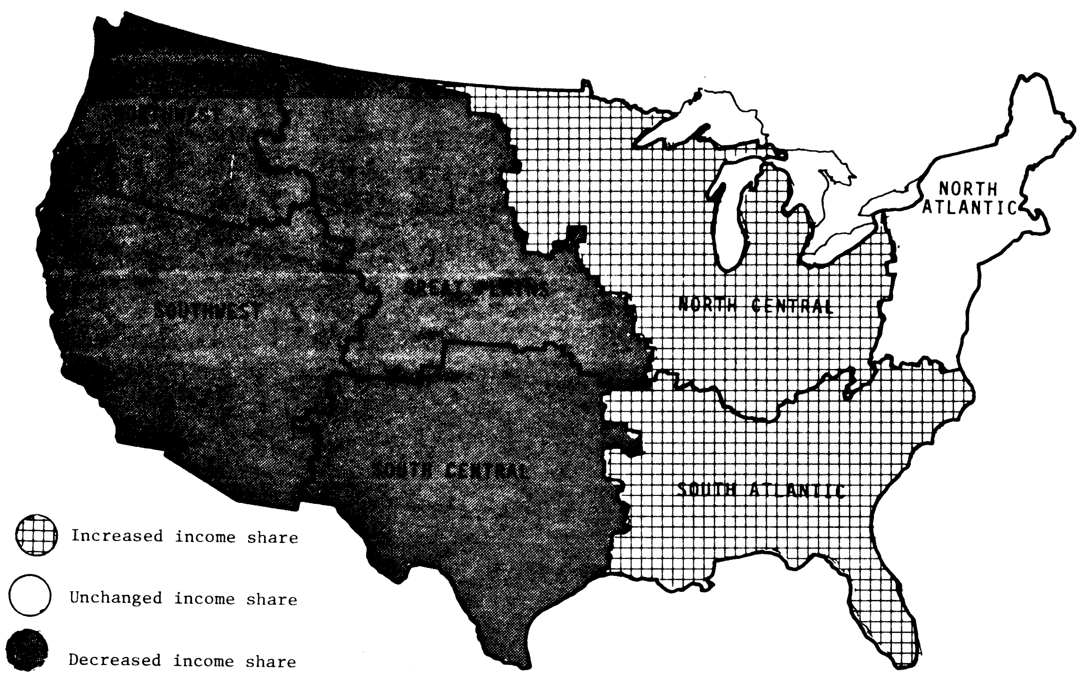

Figure 1.6. Changes in farm regional income share under 10 percent energy cut (Model C) and high energy prices (Model D) compared with the base run (Model A)

Conclusions and Implications

An energy crisis in the form of reduced energy or higher energy prices or both would have a severe long-run impact on irrigated farming in the western states. Not only do energy costs increase sharply but an energy reduction might actually prevent farmers from applying water to their irrigated crops. Of course, higher irrigation efficiency as well as reduced water application can help alleviate such a situation, but in the long-run the real hope for irrigated farming is increased agricultural exports and ample energy supplies to agriculture. Higher exports promise farmers higher returns for their output which more than offsets high energy prices. The study shows clearly that a major part of the higher exports must come from irrigated farming and increased fertilization both of which are very energy-intensive operations. United States consumers, as well as foreign buyers of U.S. farm products, should expect much higher commodity prices under an energy reduction or high energy prices.

The net environmental impacts of the energy situations analyzed is not clear. Except for the high export alternative (Model E), the energy situations analyzed would reduce the per acre application of fertilizers. Hence, they also would reduce nitrate runoff from agricultural land into the nation's waterways. The total amount of pesticide used varies only slightly between the different alternative except for Model B where a substantial increase in reduced tillage acreages is noted.

A major agricultural pollutant is sedimentation. Clearly, soil loss is a function of the number of cropland acres under cultivation. Increased land use, when not accompanied by a massive conservation effort, can be expected to increase soil loss. Furthermore, the additional land brought into production is marginal land. That land is characterized by low yields and high susceptibility to soil erosion. Thus, the substitution of land for energy which takes place under energy shortage and high energy price situations has the potential of increased soil erosion. It should be emphasized that in the long-run, however, the energy crisis would result in increased use of reduced tillage methods. Thus, additional soil loss stemming from increased land use might be offset by reduction in soil loss because of a larger proportion of cropland under reduced tillage.

The substantial increase in land use (24 million acres) under the high export alternative (Model E) would likely result in increased soil loss. In addition, high exports would also require increased fertilization, thus, would also result in increased nitrate pollution. The question as to whether or not increased agricultural pollution (because of higher exports) is justified cannot be adequately evaluated here. This question ties not only to the responsibility of U.S. agriculture to feed the world's increasing population but also to the contribution of U.S. farming to the nation's balance of payments as well as to the rest of the nation's well-being.

II. INTRODUCTION

Energy consumed by U.S. agriculture accounts for only a very small part of the total energy used yearly by the U.S. economy. However, modern farming is heavily dependent on fossil fuel for machinery, fertilizers, pesticides, and many other inputs. The recent energy crisis,therefore, is expected to have a significant and lasting impact on U.S. food production. It also will have a major impact on the "green revolution" worldwide. This will occur because high-yielding crop varieties, the basis for the "green revolution," are heavily dependent on fertilizers and irrigation, both which are highly energy-intensive processes.

The sequence of events during 1973 and 1974 that led to the energy crisis was accompanied by a sharp decline in food reserves and a rise in food costs worldwide. It is not just a coincidence that the United Nations World Food Conference, Rome, 1974, was convened in the middle of the energy crisis. At least in the foreseeable future, the world is facing multiproblem issues; how to increase food production for the growing world population while fossil fuel energy supply is rapidly declining and prices remain high.

This study does not attempt to provide an overall answer for the above issues, but it does provide some insight as to how U.S. long-run food production may be affected by the energy crisis under increasing foreign demand for U.S. agricultural products.

Objectives of the Study

The overall objective is to evaluate alternatives in energy use in agriculture and to indicate the interaction of energy sources with other inputs and their environmental impact. For example, an earlier study [11] indicates future capacity of U.S. agriculture to produce efficiently and to use its own nitrogen sources, with less imported from the chemical sector. In so doing, it could lower the indirect energy requirement for nitrogen fertilizer production. Other similar interactions prevail between energy use, technology, and resource use improvements. A large and detailed linear programming model of U.S. agriculture is used to analyze the potential behavior of agricultural production and resource use under constrained energy supplies and high energy prices.

The study is directed to the following questions: (a) Could the nation limit the amount of energy to agriculture while applying environmental restraints and still have the supply capacity needed to meet future domestic and export food and fiber demands? (b) What are the relationships between an energy shortage in agriculture and food costs? (c) How might energy constraints affect production methods in agriculture? To answer this question, alternatives such as fertilizers vs. animal wastes and legume crops, reduced tillage vs. conventional tillage and dryland farming vs. irrigated farming are analyzed. (d) What might be the changes in the regional distribution of production and how would they affect rural communities? In addition to reallocation of production as a result of the substition of dryland for irrigated farming, additional changes could occur because of differences in climate, market, location, and the transportation network. (e) If the 1972-1973 export levels of agricultural products continue into the future, can U.S. agriculture meet these demands with a limited energy supply? If not, how much more energy will be required and how can the increase be bought by expanded exports. What might be the impact of these changes on the environment? (f) How is the behavior of agricultural production affected by high energy prices and what might be the implications of production adjustments on the cost of food and fibers?

Two objective functions are used in the analysis. The first is a cost minimization objective function. It is subject to linear restraints controlling the availability of resources and prespecified domestic and export demands. The second objective function is one of energy minimization. It is subject to the same set of restraints. These two basic approaches allow us to compare the behavior of agricultural production under an energy shortage with its normal behavior under cost minimization.

A main objective of this study is to develop and apply an analytical model that allows examination of the entire set of issues relating to energy and agricultural production. These issues, brought about because of energy shortages and high energy prices,are expected to prevail in the foreseeable future.

U.S. Energy Situation and Outlook

The United States is the world's largest energy consumer. It accounts for about one-third of world energy consumption. The demand for energy in the United States has been increasing since the turn of the century. In the past 10 years energy demand has been growing at the rate of four to five percent annually. Today, U.S. per capita energy consumption is eight times the average of the rest of the world [18].

Until 1950, U.S. energy production kept pace with the ever-increasing consumption. By 1960, however, imports of crude oil and other petroleum products accounted for 15 percent of the total domestic energy consumption (Figure 2.1). Petroleum imports supplied 35 percent of the total energy consumption in 1973. At the present, energy consumption consists of

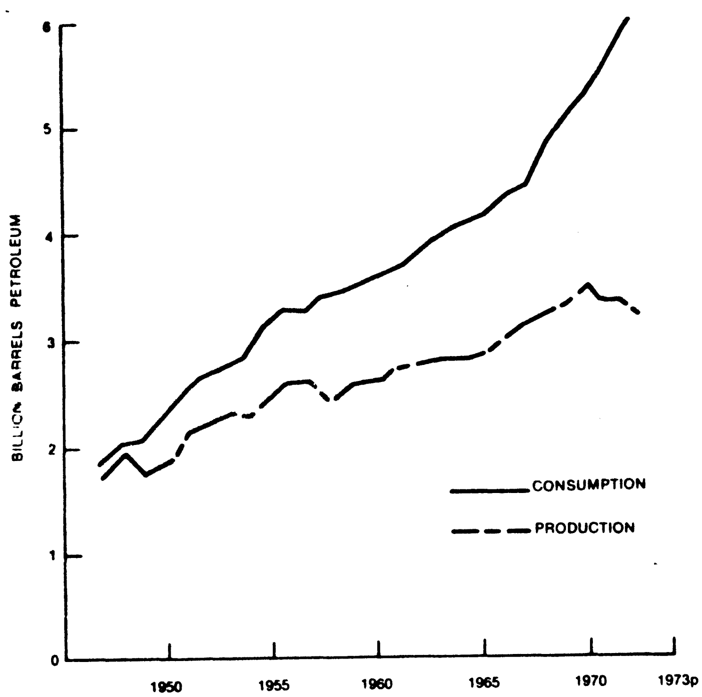

Figure 2.1. U.S. energy production and consumption 1974-73.

Source: Federal Energy Administration [18].

46 percent oil, 32 percent natural gas, and 17 percent coal, the most abundant source of energy on the North American continent. The other 5 percent is supplied by nuclear and hydroelectric power plants.

The growing dependency of the U.S. economy on foreign oil was, of course, best demonstrated by the 1973 Arab oil embargo. Not only is the United States more dependent on foreign oil than ever before, but the present world oil market is dominated by a few Middle East countries. These countries account for 60 percent of the world's known oil reserves and 70 percent of the world's oil exports [18]. The formation of the Organization of Petroleum Exporting Countries (OPEC) cartel in 1972 was the major reason for the sharp increase in world oil prices. The OPEC cartel enjoys almost a monopolistic power in setting world oil prices and production levels. Despite many predictions to the contrary, the cartel survives extremely well and is expected to be the major force in determining future world oil prices.

Energy saving, at least in the short-run, is almost the only way in which the U.S. economy can keep consuming petroleum. If consumption continues at 1972 rates, U.S. domestic oil resources will run dry in eight years while natural gas will be exhausted in 11 years [18]. Coal supplies can last for another 800 years. However, until coal liquification is technically, as well as economically, feasible not much relief is expected for the U.S. economy from this abundant energy source.

With the above grim picture, some reduction in energy supply to all sectors of the economy is expected. So far, except for some spot shortages, agriculture enjoys almost an uninterrupted fuel supply.

However, the current natural gas shortage can be expected to have an important and lasting impact on the supply and price of nitrogen fertilizers and the use of natural gas for irrigation in the Southwest. Other phases of agricultural production could also be affected as the supplies of gasoline, diesel fuel, and even electricity might not keep up with increasing demands.

Agriculture, like other sectors of the economy, may be called upon to share in energy conservation. In contrast to other sectors of the economy, increased food demands worldwide are so great that U.S. agriculture undoubtedly must expand its production in the near future. The additional energy required might be exchanged for agricultural exports. However, it is still important to determine the best ways to utilize energy in agriculture. Optimal usage can contribute both toward energy conservation and cost savings.

U.S. Food Situation and Outlook

United States agriculture has been one of the nation's most rapidly developing sectors. Its productivity advanced abruptly relative to demand in recent decades. Hence, surplus capacity was a major national problem until 1972. Recently, however, U.S. agriculture has faced a new foreign demand situation resulting from world crop shortages. For the first time since 1930, annual commodity demands have been exceeding annual supplies. This situation has brought high prices to consumers and high income to farmers. With high export demands and high agricultural prices, U.S. agricultural policy has now made a complete break from its complex of supply control, price supports, and international food aid which dominated the 1950s and 1960s. U.S. agriculture, with the cessation of these programs, has now turned towards "full capacity."

Foreign demand for U.S. agricultural products has changed drastically. Although domestic demands can be estimated with relatively minor errors for future years, foreign demands for U.S. agricultural products are highly uncertain at this time. They are subject not only to weather conditions in other countries but also are greatly affected by political decisions, the world monetary situation, population, and development programs of other countries. Even if worldwide starvation is only a possibility of the distant future, local famines have taken place for several years. Recently, drought conditions in Central Africa have caused the death of thousands.

Prior to 1972, the world as a whole experienced two decades of expanding food production and even had surpluses of grains and other foods. Per capita food production increased nearly every year in that period. Then in 1972 the index of world food production fell from 108 in 1971 (1961-65 = 100) to 104 in 1972 [17]. This decline in production concentrated in the U.S.S.R. and developing countries. The subsequent demand for U.S. agricultural commodities led to the suspension of the policy which restrained U.S. productive capacity. Annual exports of U.S. feed grains approximately doubled from 1970 to 1974, (Table 2.1), and the United States has become the world's most important exporter of feed grains (Figure 2.2), accounting for more than half of the international trade in feed grains. The United States also has become the world's leading wheat exporting country (Figure 2.3) accounting for

Table 2.1. U.S. feed grain production, domestic consumption and export 1960-1974 (million short tons) [a,b]

Year	Production	Domestic Consumption	Exports
1960	155.5	120.0	11.5
1961	139.8	120.8	14.7
1962	141.7	119.2	15.4
1963	153.8	116.4	16.1
1964	134.2	111.6	18.1
1965	158.0	126.8	25.8
1966	159.0	127.0	21.4
1967	178.9	128.9	20.2
1968	170.5	135.5	16.5
1969	177.4	142.4	14.6
1970	160.1	138.3	19.8
1971	207.7	149.1	21.0
1972	199.9	155.3	35.8
1973	205.0	152.7	44.3
1974	165.3	117.5[c]	37.5
1975	202.4	131.6[d]	40.4

[a]Source: United States Department of Agriculture [44].

[b] Includes corn, sorghum, oats, and barley.

[c] Preliminary.

[d] Based on August indications.

41 percent of the world's wheat exports in 1974, while producing only 14 percent of the world's supply [44]. Similar situations have developed in other commodities such as soybeans and cotton.

The high prices for agricultural commodities and the large quantities exported resulted in more than a 300 percent increase in the value of U.S. agricultural exports between 1970 and 1974 (Figure 2.4). This, in turn, increased agriculture's net contribution to the balance of payments

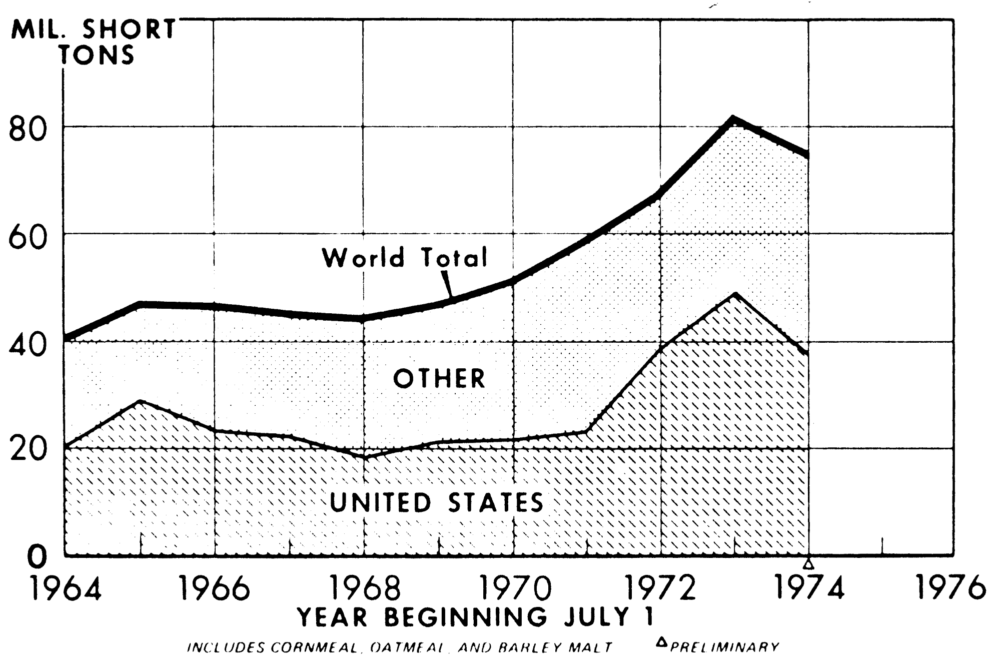

Figure 2.2. World exports of coarse grains

Source: USDA [44].

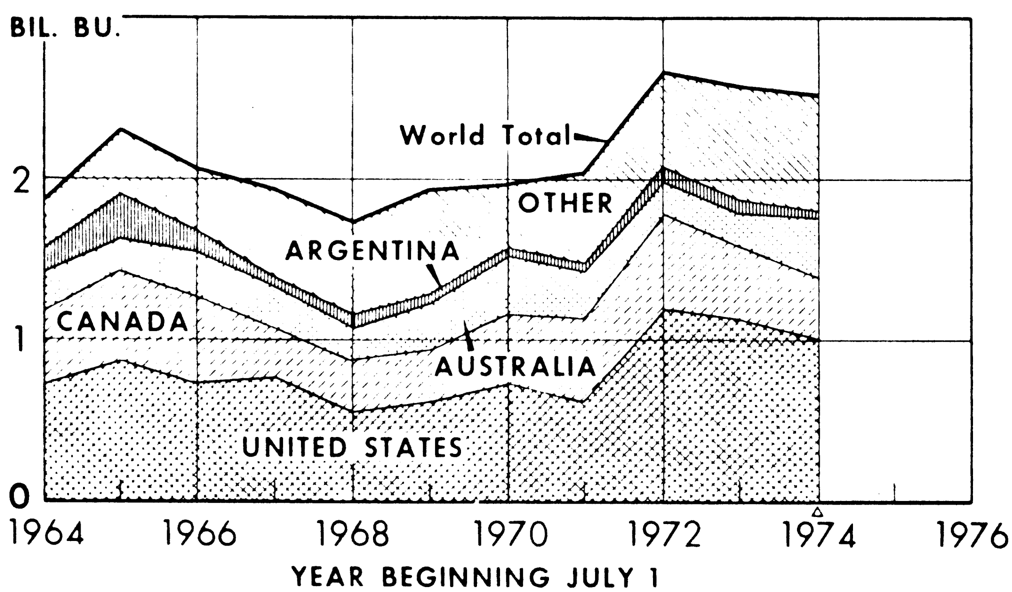

Figure 2.3. World exports of wheat and flour (by county)

Source: USDA [44].

from less than one billion dollars in 1970 to more than eight billion dollars in 1973 [44]. Hence, U.S. agriculture has become not only the world's most important food supplier but also has a major responsibility for the improvement in the nation's international economic position.

The World Food Conference, sponsored by the United Nations and held in Rome 1974, was an expression of growing international concern about the critical nature of the world's food situation. Nineteen substantive resolutions and a concluding resolution calling for follow-up

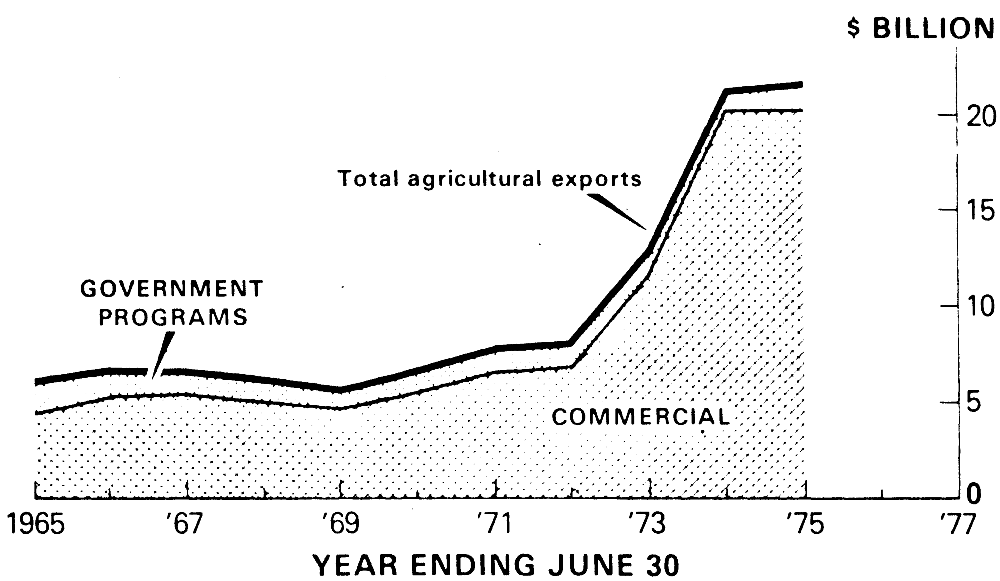

Figure 2.4. U.S. agricultural exports: commercial and under government programs.

Source: USDA [44].

action were adopted at the conference. The conference agreed that a substantial increase in food production is needed in the developing countries and that short-term increases are needed in the developed countries in order to lessen the world's current vulnerability to crop shortfalls. One of the proposals for greater food production calls for a survey of land resources to determine potential new food production. Another resolution (the World Soil Character and Land Capability Assessment) recommends that governments apply soil protection and conservation measures and make all attempts to increase agricultural production [17]. A resolution concerning fertilizer also was passed. Among other things, it says "All countries are requested to introduce fertilizer quality standards, promote the most efficient use of fertilizers, including utilization of nonmineral sources of plant nutrients, and to voluntarily reduce noncritical uses" [17].

Energy Use in Agricultural Production

Sunlight provides the energy for the biochemical process in plants which convert carbon dioxide, water, nitrogen, and other elements into the food building blocks of sugar, starches, and plant proteins. However, sunlight is only a small part of the total energy required in food production. Labor energy, animal energy, and most important fossil fuel energy are as necessary as sunlight for efficient food production methods. Modern agriculture typically uses a much larger proportion of fossil fuel energy than does traditional agriculture. For example, Pimentel et al., [37] show that when solar energy is excluded, 99.89 percent of the energy input in rice production in the United States comes from fossil fuel. In the Philippines, on the other hand, only 31 percent of the energy for rice production is obtained from fossil fuel. The high energy intensity of U.S. agriculture is accompanied, however, by high yields. Rice yield in the United States is about three and a half times higher than in the Philippines.

It is quite clear that modern farming technology based on extensive use of fossil fuel energy is a major factor behind the high productivity of U.S. agriculture. Modern, farming involves extensive use of machinery, chemical fertilizers, pesticides, crop drying, irrigation, and transporting of raw materials and products. Moreover, the time element of farming makes agricultural production extremely vulnerable to an energy shortage. It is estimated that on-farm U.S. agriculture energy requirements are less than 3 percent of the total U.S. yearly energy needs [16]. Therefore, even if the amount of energy saved in agriculture proved to be substantial, it will not have a noticeable effect on the total U.S. energy demand. The Economic Research Service (ERS), U.S. Department of Agriculture, estimated that of the total energy used by agriculture in 1970, farm production took 22 percent; family living, 12 percent; food processing, 28 percent; marketing and distribution, 18 percent; and selected input industries, 20 percent [16]. Hence, most of the energy consumed in food production takes place off the farm.

Summary of studies

Even before the 1973 energy crisis, several studies were made of the relationships between agricultural production and energy. Since it is impossible to discuss all previous studies on energy and agriculture in the space available, only a few of the most important studies will be summarized.

Perelman's "Farming with Petroleum" [35] points out that while U.S. agriculture is doing an amazingly efficient job in food production, this accomplishment results through aid of other sectors that supply agriculture with machinery and other inputs. According to Perelman, measuring efficiency by output per farm worker does not capture the complexity of agricultural production which transforms energy, fertilizers, labor, and other resources into food and fibers. High labor efficiency in agriculture is achieved mainly by reduction in the efficiency of other inputs, especially energy. Perelman suggests that now, facing an energy crisis, we might do well to measure efficiency in terms of output per unit of energy instead of output per unit of labor. Doing so, according to Perelman, reveals that U.S. agriculture comes out very poorly.

Perelman fails to discuss economic efficiency of agriculture in terms of other scarce resources such as water and land. At present, the United States faces a world food shortage as well as an energy shortage. Hence, adopting technologies that increase energy efficiency but reduce output, as suggested by Perelman, must be considered with caution.

Hirst's "Energy Use for Food in the United States" [23] provides some of the initial estimates on the amount of energy used in food-related activities in the United States from agricultural production to final consumption. Based on 1963 energy input/output tables [22], Hirst concludes that 12 percent of the total 1963 energy consumed in the United States was required to grow, process, transport, wholesale, retail, refrigerate, and prepare food in homes. Agricultural production in 1963 accounted for only one-fifth of the energy used for food (Figure 2.5). In the food system as a whole, meat, poultry, and fish products consumed the largest amount of energy (Figure 2.6). On the average, 6.4 BTU[1] of fossil fuel energy was consumed in delivering one BTU of food energy to final demand in 1963. However, this ratio varies greatly among energy yielding products such as sugar, fat, oil, cereal, and fresh vegetables (Figure 2.7). Processed vegetables require three times more energy than fresh vegetables to supply one unit of energy in food (Figure 2.8). Quite a different situation exists with respect to production of food protein. On the average, 835 BTUs of primary energy were required to supply one gram of protein to final food demand in 1963 (Figure 2.8). Fresh vegetables, while very energy efficient in supplying food energy, are very energy inefficient in supplying protein.

Pimentel et al., "Food Production and the Energy Crisis" [36], constructed energy budgets for U.S. corn grain for 1945, 1950, 1954, 1959, 1964, and 1970. They indicate that while the average corn yield increased from 34 bushels per acre in 1945 to 81 bushels per acre in 1970 (140 percent increase), per acre energy inputs increased 220 percent. Hence, the yield in corn calories, decreased from 3.28 KCAL per one fossil fuel KCAL input in 1945, to a yield of 2.52 KCAL in 1970, a

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[1] One BTU (British Thermal Unit) is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit at or near 39.2° F.

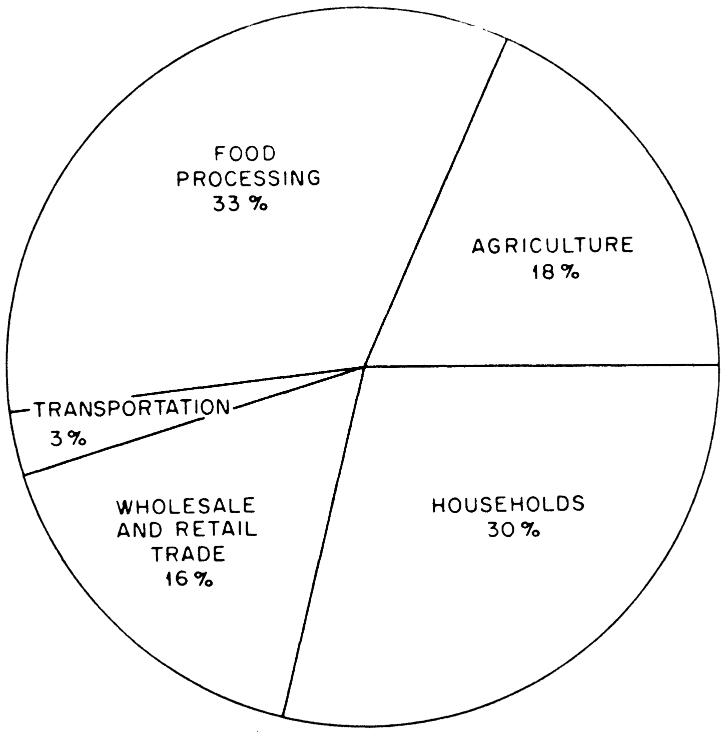

Figure 2.5. Distribution of total energy requirements for personal consumption of food in the United States, 1963

Source: Hirst [23].

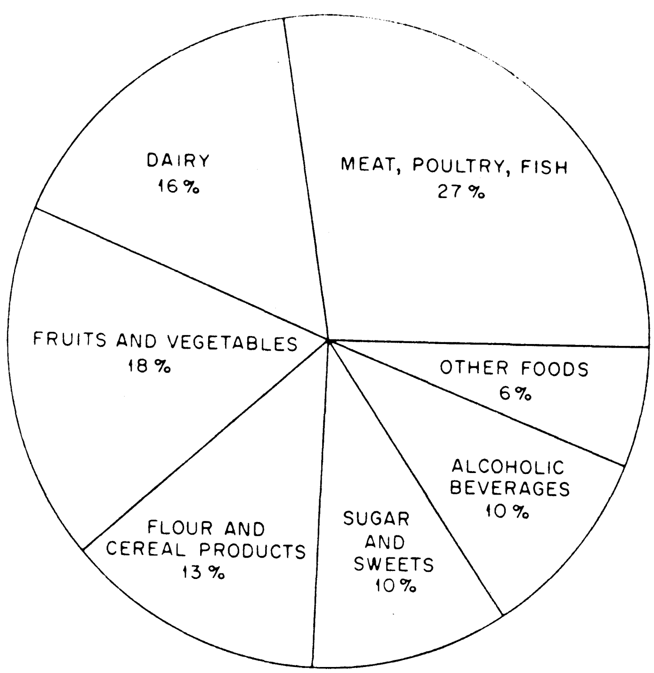

Figure 2.6. Distribution of primary energy consumption for food by major food groups, 1963

Source: Hirst [23].

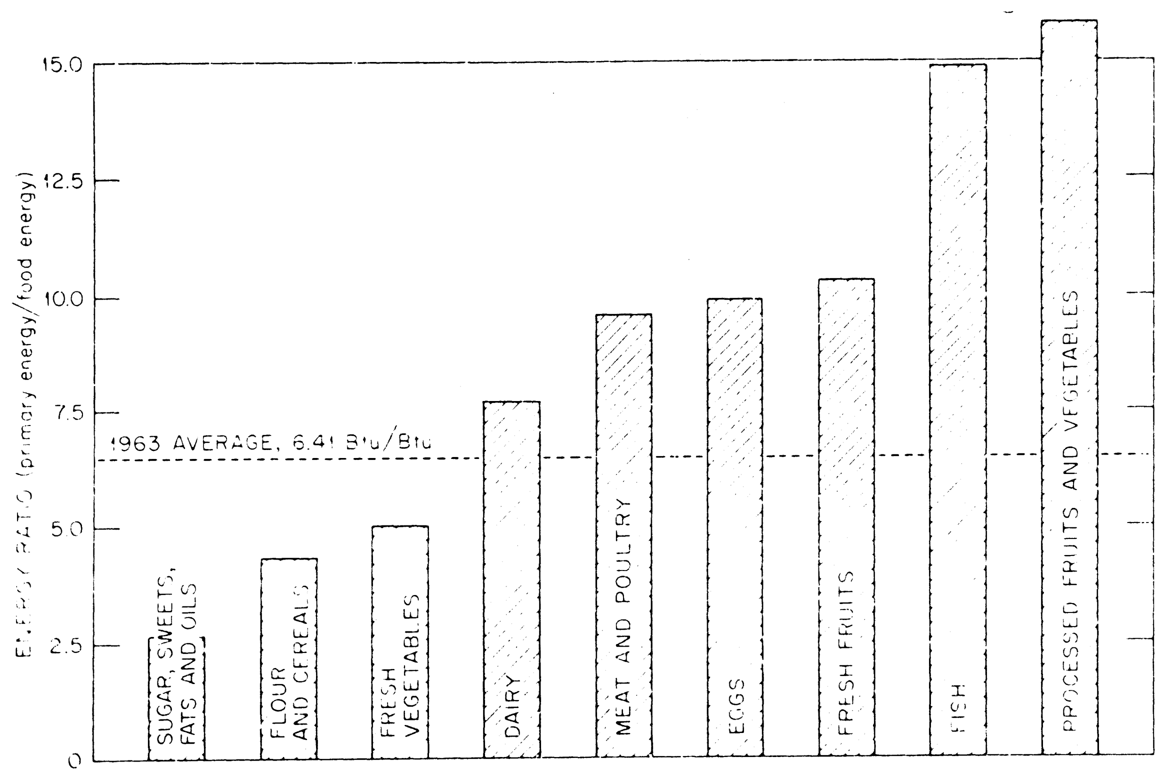

Figure 2.7. Ratio of primary energy use to food energy content for major food groups, 1963

Source: Hirst [23].

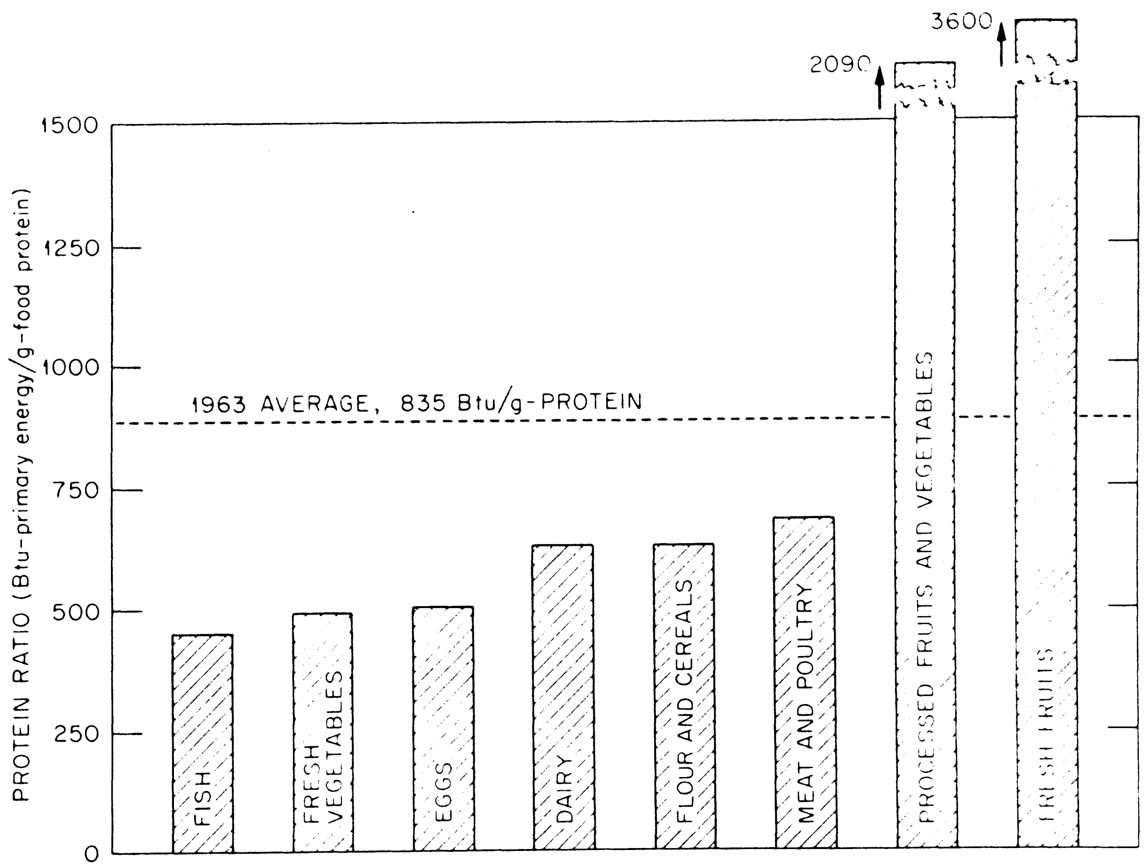

Figure 2.8. Ratio of primary energy use to protein content for major food groups, 1963

Source: Hirst [23].

30 percent decline. On the other hand, the yield in corn calories per one KCAL of man labor increased from 241 KCAL in 1945 to 1493 KCAL in 1970, a sixfold increase (Table 2.2). Thus, Perelman's [35] claims of changing efficiencies in agriculture seem justified.

Pimental et al., [36] conclude that to feed the world's four billion people while employing the modern intensive agricultural technology used in U.S. corn production, an energy equivalent of 1.2 billion gallons of fuel per day would be required. According to their study, given known world petroleum reserves, food production alone will use up all petroleum reserves in a mere 29 years [36].[1]

One of the most extensive studies on energy and agriculture was conducted for the Subcommittee on Agricultural Credit and Rural Electrification of the United States Senate by the Economic Research Service (ERS), U.S. Department of Agriculture. The study, "The U.S. Food and Fiber Sector: Energy Use and Outlook," examines the energy consumed in farm production, farm family living, food processing, marketing and distribution, and selected input industries in 1970 [16]. It estimates that agricultural energy needs increased at about 4 percent per year, approximately the same rate at which the entire nation increases energy consumption. By 1980 energy demands by the food and fiber industries are projected to rise 11.3 percent if the ratio of output per energy input remains at the 1970 level. In addition to a breakdown of energy by type of industry, the study gives a breakdown of the energy sources in 1970 and 1980 (Table 2.3).

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[1]A detailed criticism of Pimental et al. [36] is presented in Nelson, Burrows and Stigler [31].

Table 2.2. Estimated energy inputs in U.S. corn production for selected years [a]

Inputs	1945	1950	1954	1959	1964	1970
				(KCAL per hectare)[b]		
Labor	31,022	23,947	22,859	19,049	14,695	11,974
Machinery	444,600	617,500	741,000	864,500	1,037,400	1,037,400
Fuel	1,339,800	1,521,630	1,703,460	1,789,590	1,885,290	1,971,420
Nitrogen	140,800	299,200	528,000	809,600	1,144,000	2,200,000
Phosphorus	25,520	35,090	41,470	57,420	63,800	111,650
Potassium	13,200	24,200	44,000	74,800	101,200	147,400
Seeds for planting	77,440	91,520	112,640	133,760	147,840	147,840
Irrigation	103,740	128,440	148,200	170,430	187,720	187,720
Insecticides	0	2,662	8,228	18,876	27,104	27,104
Herbicides	0	1,452	2,662	6,776	10,406	27,104
Drying	9,880	34,580	74,100	163,020	247,000	296,400
Electricity	79,040	133,380	247,000	345,800	501,410	765,700
Transportation	49,400	74,100	111,150	148,200	172,900	172,900
Total inputs	2,314,442	2,987,701	3,784,769	4,601,821	5,540,765	7,104,612
Corn yield	7,504,640	8,388,160	9,053,440	11,922,240	15,012,800	17,881,600
KCAL return/KCAL input	3.24	2.81	2.39	2.59	2.71	2.52

[a]Source: Pimentel et al., [37].

[b]One hectare is approximately 2.5 acres.

Table 2.3. BTU used in U.S. food and fiber sector by major types of industries and energies, in 1970 and 1980 [a]

Item	1970[b] Trillion BTU	1970[b] Percent	1980 Trillion BTU	1980 Percent	Changes in percent
Type of industry or use					
Farm production	1,051.4	22.5	1,095.3	21.1	+4.2
Farm family living	554.6	11.9	499.2	9.6	-10.0
Food & kindred product processing	1,302.9	27.9	1,548.3	39.8	+19.8
Marketing & distribution	832.7	17.9	988.9	19.0	+18.8
Input manufacturing[c]	925.3	19.8	1,063.8	20.5	+15.0
Total	4,666.9	100.0	5,195.5	100.0	+11.3
Type of energy					
Liquid fuels and LP gas	2,334.5	50.0	2,502.3	48.2	+7.2
Residual fuel oil	97.5	2.1	115.0	2.2	+17.9
Natural gas	1,414.4	30.3	1,652.7	31.8	+16.8
Electricity	643.0	13.8	738.6	14.2	+14.9
Coal and coke	165.8	3.6	173.6	3.3	-4.7
Other	11.6	0.2	13.3	0.3	+14.7
Total	4,666.9	100.0	5,195.5	100.0	+11.3

[a]Source: ERS [16].

[b]For some industries data are for 1971, 1972, or 1973.

[c]Includes estimates for six selected industries.

The study also provides estimates of fuel consumption by crops and livestock for 1973 and projections for 1980 under low and high exports. Under high exports the study estimates that 19 percent of all the fuel consumed by crop and livestock production in 1980 will be devoted to agricultural exports (1.6 billion gallons out of 8.3 billion gallons). The study evaluates some energy conservation methods in agriculture and concludes that "reduced tillage practices are the major means of achieving these goals." The ERS study also evaluates the effect of higher energy prices on food costs. Because energy cost is only a small proportion of the total input costs, the study concludes that doubling fuel prices will increase food prices by only 5 percent. However, this is true only for the direct effects of fuel price changes. If we consider the indirect effect, such as higher fertilizer prices, the increase in food costs would be substantially larger than the changes obtained by the study.

The U.S. energy situation in 1973 resulted in a large number of state agricultural energy studies. These studies develop detailed estimates of energy requirements for crops and livestock. Most of the studies allow for only a little discussion on how the changing energy situation might influence the economics of agricultural production. Some good state studies are "Energy Requirements for Agriculture in California" [3], "Energy Requirement for New York State Agriculture" [20], "Energy Uses in Nebraska Agriculture" [27], and "Energy Consumption, Conservation, and Projected Needs for Texas Agriculture" [4].

Several studies also have been conducted on the relationship between energy consumption and a specific input or a farming operation. These studies cover the use of energy in irrigation, fertilizers, pesticides, crop drying, and tillage practices. Dvoskin, Nicol, and Heady's "Energy Use for Irrigation in the 17 Western States" [12] quantifies by region the amount of energy required to obtain and apply an acre-foot of water in the Western United States. White's "Fertilizer-Food-Energy Relationships" [50] gives information on energy requirements in fertilizer production and discusses the relationships between food production and fertilizer demands. Nalewaja's "Energy Requirements of Various Weed Control Practices" [30] described energy needs in relation to different weed control methods ranging from hand labor to herbicides. He shows that elimination of herbicides on corn alone would require 17.7 million people to hand weed during the weeding period to obtain the same level of weed control achieved with herbicides. Whittmuss, Olson, and Lane's "Energy Requirements for Minimum Tillage as Compared to Conventional Tillage" [51] demonstrates that energy inputs for field operations in corn and sorghum can be reduced as much as 83 percent by the use of minimum tillage practices. Raikes and Harris' "Corn Prices, The Fuel Shortage and Optimal Corn Harvesting Strategies" [38] concludes that "corn price changes have a much greater impact on the optimal harvest strategy than do propane price changes." The propane demand for drying is very inelastic with respect to propane price, but quite elastic with respect to corn price.

The most comprehensive publication of studies on energy in agriculture is "Energy in U.S. Agriculture: A Compedium of Energy Research Projects" [13], which contains abstracts of approximately 1,250 entries of ongoing or recently completed research projects and article abstracts related to energy requirements and energy conservation practices and technology.

III. MODEL DESCRIPTION

The interregional model used in this study is a reduced version of the linear programming model developed at the Center for Agricultural and Rural Development (CARD) for the 1975 National Water Assessment [29]. The analysis of the study is made for 1985, a time span long enough to allow farming methods to adjust to a changing energy situation. Under most of the alternatives analyzed, the model minimizes the national cost of crop production and transportation. This cost minimization procedure is subject to a set of primary restraints corresponding to land, water, and energy supplies by regions, production requirements by location, the nature of production, and a final set of restraints controlling the demand sector through commodity supply-demand equilibriating relationships. The cost minimization model also is one of competitive equilibrium wherein resources receive their market rate of return. Return to land is determined endogenously in the model.

Under one alternative, instead of cost minimization, the model minimizes the total energy (measured in 1,000 KCAL) used for crop production and transportation. There are 880 restraints (rows) in the model.

Activities in the model simulate crop rotations, water transfer and distribution, commodity transportation, and nitrogen and energy supplies. There are 10,700 activities in the model. Endogenous crop activities are specified for corn grain, sorghum grain, corn silage, sorghum silage, wheat, soybeans, cotton, sugar beets, oats, barley, legume and nonlegume hay. The projected production levels of all other crops (fruits, vegetables, tobacco, potatoes, rice, peanuts, buckwheat, etc.) and all livestock including beef cows, beef feeding, dairy cows, hogs, turkeys, broilers, egg production, sheep and lambs, and others are exogenously determined.

Regional Delineation

Two sets of regions are utilized in the analysis--producing areas, and market regions. The boundaries of the market regions are defined from a compatible subset of producing areas and reflect the interregional nature of the study.

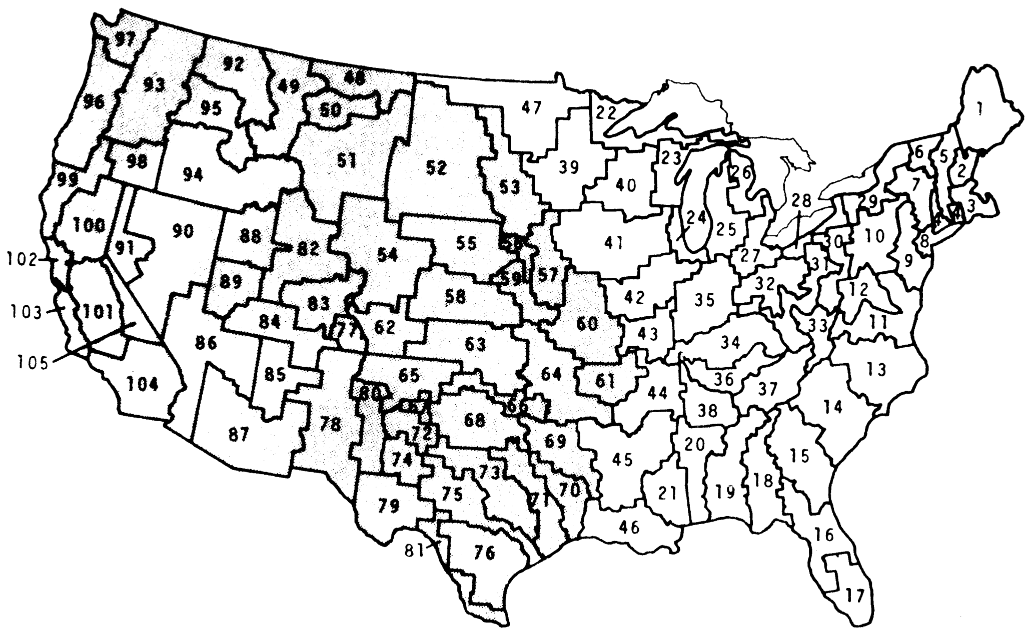

Figure 3.1. The 105 producing areas with irrigated lands (shaded areas) in the West

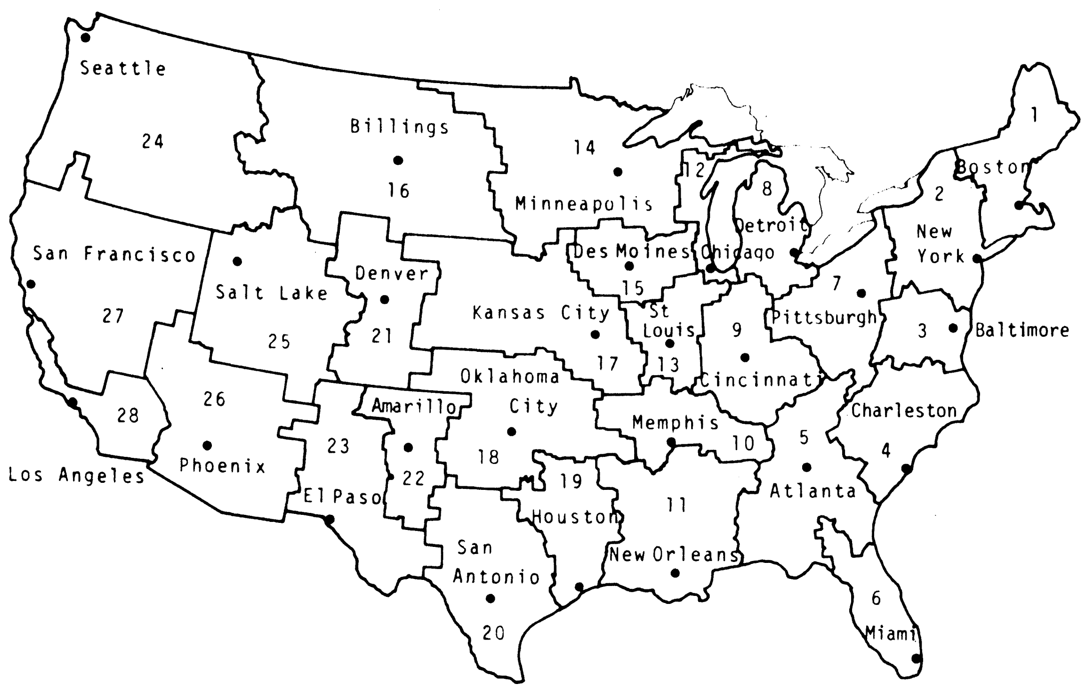

Figure 3.2 . The 28 market regions

The producing areas (PA)

The 105 producing areas (Figure 3.1) are the basic units of the programming model. These areas are derived from the Water Resource Council's 99 aggregated subareas [48]. The producing areas are identical except for six aggregated subareas (ASA's) which are subdivided to be more consistent with agricultural production in these regions. Each producing area is an aggregation of contiguous counties approximating the ASA's boundaries. Producing areas 48 to 105 serve dual purposes since they define both agricultural production and water supply regions (Figure 3.1).

The market regions (MR)

The 28 market regions (Figure 3.2) are an aggregation of the 105 producing areas. Each market region represents an established commercial and transportation center and serves as the hub of commodity demands and transport linkages. The market regions also simulate the market place for two important agricultural inputs in this study, nitrogen and energy.

The major zones

For reporting purposes only, another set of regions is defined by aggregating adjacent market regions into seven major zones (Figure 3.3). The major zones are: North Atlantic, South Atlantic, North Central, South Central, Great Plains, Southwest, and Northwest.

Figure 3.3. The seven major zones

The Objective Functions

Two objective functions are utilized in the study. The first objective function minimizes the total cost of crop production (labor, machinery, pesticides, fertilizers, energy, and water) and the cost of transporting raw agricultural products from location of production to the consumption centers defined in terms of market regions. The second objective function minimizes the total amount of energy consumed in crop production and transportation. The energy minimized includes (a) energy consumed directly by crops such as diesel fuel for machinery and liquid petroleum gas (LPG) for crop drying and, (b) some energy used indirectly such as natural gas for fertilizers, energy for pesticides, electricity for water pumping and diesel fuel for commodity transportation.

Both objective functions are subject to predetermined domestic and foreign commodity demands in 1985, availability of land and water resources, and minimum and maximum regional production requirements. Under one of the alternatives, the cost minimization objective function is also subject to a set of regional and national energy restraints. The cost minimization objective function is of the form:

$$\min OBJ1 = \sum_i \sum_j \sum_k RC_{ijk} X_{ijk} + \sum_m PN_m NB_m + \sum_m PN_m NL_m + \sum_n WC_n WB_n$$

$$+ \sum_n WTC_n WT_n + \sum_p \sum_t TC_{pt} T_{pt} + \sum_m \sum_s ENC_{ms} EN_{ms} \qquad (1)$$

The energy minimization objective function is of the form:

$$\min OBJ2 = \sum_i \sum_j \sum_k KCC_{ijk} X_{ijk} + KCN \sum_m NB_m + \sum_p \sum_t KCT_{pt} T_{pt} \qquad (2)$$

i=1,...,105 for the producing areas,
j=1,..., 6 for the six levels of fertilizer-tillage practices,
k=1,...,330 for the crop rotations in producing area i,
m=1,..., 28 for the 28 market regions,
n=48,..,105 for the 58 water supply regions,
p=1,..., 6 for the six commodities transferred,
t=1,...,176 for the transporting routes defined, and
s=1,..., 4 for the four types of energy sources (diesel, natural gas, LPG and electricity).

where:

RC_{ijk} is the cost, dollars per acre, of crop activity k with fertilizer-tillage practice j in producing area i;

X_{ijk} is the level of crop activity k with fertilizer-tillage practices j in producing area i;

PN_m is the price of nitrogen fertilizer, dollars per pound, in market region m;

NB_m is the level of the nitrogen buying activity in market region m;

NL_m is the amount of livestock residue expressed as nitrogen fertilizer equivalent utilized by crops in market region m;

WC_n is the price of water, dollars per acre-foot, in water supply region n;

WB_n is the level of water buying activity in water supply region n;

WTC_n is the cost, dollars per acre-foot of water transfer from water supply region n;

WT_n is the level of water transfer through natural flow, water exports or interbasin transfer from water supply region n;

TC_{pt} is the transportation cost per unit of commodity P over route t;

T_{pt} is the number of units of commodity p transferred over route t;

ENC_{ms} is the cost, dollars per unit, of energy source s in market region m;

EN_{mc} is the level of energy source s utilized in market region m;

KCC_{ijk} is the energy needed, 1000 KCAL, for machinery, pesticides, nonnitrogen fertilizers, and irrigation by crop activity k with fertilizer-tillage practice j in producing area i;

KCN is the energy needed, 1000 KCAL, to produce one pound of nitrogen fertilizer; and

KCT_{pt} is the energy needed, 1000 KCAL, to transfer a unit of commodity p over route t.

Restraints

Restraints in the model control availability of land, water, nitrogen fertilizers, and energy; commodity production and utilization for domestic and export demands; regional location of production; and farming practices restraints controlling the regional acreage proportion of reduced tillage. The restraints in the model are defined either at the producing area, market region, water supply region, or national level.

Restraints at the producing area level

Two sets of restraints are defined at the producing area level. These sets control the availability of dryland and irrigated cropland. The cropland available in each producing area is adjusted for the exogenous cropland requirements in 1985 [29][1]. For each producing area the availability of cropland is controlled by restraints of the form:

$$\sum_{d} X_{ijd} \leq CLD_i \tag{3}$$

$$\sum_{r} X_{njr} \leq CLR_n \tag{4}$$

[1]This adjustment is made by reducing the land available for endogenous crops by the acreage required for exogenous crops in each region by 1985.

i=1,...,105 for the producing areas,
j=1,..., 6 for the six levels of fertilizer-tillage practices,
d=1,...,330 for the dryland or irrigated crop rotations defined on dryland,
r=1,...,330 for the irrigated crop rotations, and
n=48,..,105 for the 58 water supply regions.

where:

X_{ijd} is the level of dryland crop activity d with fertilizer-tillage practice j in producing area i;

X_{njr} is the level of irrigated crop activity r with fertilizer-tillage practice j in water supply region n;

CLD_i is the acres of dry cropland available for endogenous crops in producing areas i; and

CLR_n is the acres of irrigated cropland available for endogenous crops in water supply region n.

Restraints at the water supply region level

One restraint is defined in each of the water supply regions (producing areas 48 to 105). This restraint balances the dependable water supply in the region, including interbasin transfers, natural flow and runoff, and the many water uses in 1985. Water consumed onsite, water used by livestock and exogenous crops, municipal and industrial uses of water, and water exports are predetermined exogenous to the model. An adequate water balance is obtained by requiring the water supply to be at least as great as the sum of the above exogenous uses and the endogenous crop demands. For the complete explanation of the water sector in the model see Colette [4].

Restraints at the market region level

Five sets of restraints are defined at the market region level. These restraints include commodity transfer restraints, regional location of production restraints, nitrogen market restraints, energy market restraints, and tillage practice restraints.

Commodity demand restraints   These restraints simulate the market place for the following endogenous commodities: corn grain, sorghum grain, barley, oats, wheat, oilmeals, nonlegume hay, legume hay, and silage. The producing areas within each of the market regions supply their commodities directly to their respective market region commodity demand restraints. Other commodity demand restraints in other market regions are linked together by commodity transportation activities. For each one of the above commodities in each of the 28 market regions the restraint is of the form:

$$\sum_k Y_{ijk} X_{ijk} \pm T_t \geq CD \tag{5}$$

i=1,...,7 for the number of producing areas in the given market region,
j=1,...,6 for the six levels of fertilizer-tillage practices,
k=1,...,330 for the crop rotations in the producing areas belong to the given market region, and
t=1,...,176 for the transportation routes defined.

where:

Y_{ijk} is the per acre yield of the k crop activity with fertilizer-tillage practice j in producing area i;

X_{ijk} is the level of crop activity k with fertilizer-tillage practice j in producing area i;

T_t is the number of units of the given commodity transfered in (+) or out (-) of the market region; and

CD is the sum of the domestic, livestock, and export demands for the given commodity in the market region in 1985.

<u>Regional production restraints</u> One set of restraints is defined at the market region level to provide for minimum and maximum levels of crop production within each region. This set of restraints approximates the immobility of crop production due to economic factors such as risk aversion, uncertainty as to future farm prices, and other noneconomic factors. The minimum and the maximum production levels are specified in terms of the 1969 crop acreage [45] for the following crops: corn grain, sorghum grain, barley, oats, wheat, soybeans, cotton, and sugar beets. Both irrigated and dryland crops can be used to satisfy the production restraints. For each of the above crops, these restraints have the general form:

$$L_m \leq \sum_{ijk}\sum\sum X_{ijk}W_{jk} \leq U_m \qquad (6)$$

$i=1,\ldots,7$ for the producing areas in market region m,
$j=1,\ldots,6$ for the six levels of fertilizer-tillage practices,
$k=1,\ldots,330$ for the crop rotation in producing area i, and
$m=1,\ldots,28$ for the 28 market regions.

where:

L_m is equal to 70 percent of the 1969 crop acreage in market region m;

X_{ijk} is the level of crop activity k with fertilizer-tillage practice j in producing area i within market region m;

W_{jk} is the crop weight in rotation k with fertilizer-tillage practice j;

U_m is equal to 250 percent of the 1969 crop acreage in market region m.

Nitrogen fertilizer transfer restraints Another set of restraints acts as a market place for the supply and demand of nitrogen fertilizers. Nitrogen is supplied from livestock by-products, from commercially produced fertilizers, and from the fixation process of the legume crops. Nitrogen is used by the endogenous crop activities. In addition, a predetermined amount is allocated for the exogenous crops. For a given market region, each nitrogen restraint is of the general form:

$$- \sum_i \sum_k X_{ijk} F_{ijk} + NB_m + NL_m \geq EN_m \qquad (7)$$

i=1,...,7 for the producing areas in market region m,
j=1,...,6 for the six levels of fertilizer-tillage practices,
k=1,...,330 for the crop rotation in producing area i, and
m=1,...,28 for the 28 market regions.

where:

X_{ijk} is the level of crop activity k with fertilizer-tillage practice j in producing area i within market region m;

F_{ijk} is the net nitrogen required annually, pound per acre, by crop activity k with fertilizer-tillage practice j in producing area i;

NB_m is the amount of commercially produced nitrogen, in pounds, purchased for the endogenous crops in market region m;

NL_m is the amount of livestock by-products, expressed as N equivalent, utilized annually by crops in market region m; and

EN_m is the amount of nitrogen fertilizers needed for the exogenous crops in market region m.

Energy transfer restraints Five sets of restraints are defined in each market region to act as a market place for energy sources (Figure 3.4). These restraints are defined for diesel fuel (DIESEL, in gallons), natural gas (NAT. GAS, in 1000 cubic-feet), liquid petroleum gas (LPG, in gallons), electricity (ELCT, in KWH), and total energy market in terms of 1000 KCAL of energy.[1] The regional energy needs are supplied by energy buying activities (DSLB, NGAS, LPGB, ELCB, CALB) which withdraw energy from the national energy market restraints. Energy is used by crop activities, transportation activities, and commercial nitrogen fertilizer supply activities. In each market region the above five restraints are of the general form:

Diesel fuel (DIESEL)

$$- \sum_{i}\sum_{j}\sum_{k} X_{ijk} EC_1 - \sum_{p}\sum_{t} T_{pt}\, ET_{1pt} + EB_1 \geq 0 \qquad (8)$$

Natural gas (NAT. GAS)

$$- \sum_{i}\sum_{j}\sum_{k} X_{ijk}\, EC_2 - NB_m\, EN_2 + EB_2 \geq 0 \qquad (9)$$

Liquid petroleum gas (LPG)

$$- \sum_{i}\sum_{j}\sum_{k} X_{ijk}\, EC_3 + EB_3 \geq 0 \qquad (10)$$

Electricity (ELCT)

$$- \sum_{i}\sum_{j}\sum_{k} X_{ijk}\, EC_4 - NB_m\, EN_4 + EB_4 \geq 0 \qquad (11)$$

Total energy (KCAL)

$$- \sum_{i}\sum_{j}\sum_{k} X_{ijk}\, EC_5 - \sum_{p}\sum_{t} T_{pt}\, ET_{5pt} - NB_m\, EN_5 + EB_5 \geq 0 \qquad (12)$$

---

[1] See Appendix F for conversion tables.

	CORN 15	TRAN 1517	NBUY 15	NBUL 15	DSLB 15	NGAS 15	LPGB 15	ELCB 15	CALB 15	CORN 17	NBUY 17	NBUL 17	WTRB 17	DSLB 17	NGAS 17	LPGB 17	ELCB 17	CALB 17	DSLB 00	NGAS 00	LPGB 00	ELCB 00	CALB 00	Row Sign	RHS
OBJECTIV-F	+90	.14	.100	.100	-.001	-.061	-.001	-.001	.000	140	.13	.13	9.14	.012	-.067	-.002	-.002	.000	.169	.200	.146	.004	.000	N	
DRYLAND-15	+1.0																							L	24,982
NITRØ-15	-97		+1.0	+1.0																				G	0.0
CRN-15	+107	-.10																						G	1,024,037
DIESEL-15	-14.6	-.03			+1.0																			G	0.0
NAT.GAS-15	-.07		-.03			+1.0																		G	0.0
LPG-15	-10.1						+1.0																	G	0.0
ELCT-15	-4.6		-.12					+1.0																G	0.0
KCAL-15	-804	-.93	-8.6						+1.0															G	0.0
IRRLAND-17										+1.0														L	5,075
WATER-17										-1.5			+1.0											G	0.0
NITRØ-17										-61	+1.0	+1.0												G	0.0
CRN-17		+1.0								+122														G	375,561
DIESEL-17										-19.9				+1.0										G	0.0
NAT.GAS-17										-1.4	-.03				+1.0									G	0.0
LPG-17										-22.26						+1.0								G	0.0
ELCT-17										-151							+1.0							G	0.0
KCAL-17										-2,093	-8.6							+1.0						G	0.0
DIESEL-00					-1.0									-1.0					+1.0					G	0.0
NAT.GAS-00						-1.0									-1.0					+1.0				G	0.0
LPG-00							-1.0									-1.0					+1.0			G	0.0
ELCT-00								-1.0									-1.0					+1.0		G	0.0
KCAL-00									+1.0									+1.0					-1.0	L	0.0
Upper Bounds				573,160								659,800	2136												

Figure 3.4. CARD-NSF energy model: A schematic representation

$i=1,\ldots,7$ for the producing areas in market region m,
$j=1,\ldots,6$ for the six levels of fertilizer-tillage practices,
$k=1,\ldots,330$ for the crop rotations in producing area i,
$m=1,\ldots,28$ for the 28 market regions,
$p=1,\ldots,6$ for the 6 commodities transferred,
$t=1,\ldots,176$ for the transporting routes defined, and
$n=1,\ldots,n$ for the 5 energy sources required.

where:

X_{ijk} is the level of crop activity k with fertilizer-tillage practices j in producing area i;

EC_n is the per acre energy requirement coefficients of crop rotation X_{ijk};

T_{pt} is the number of units of commodity p transferred over route t;

ET_{npt} is the energy requirement coefficient for transporting commodity P over route t;

EB_n is the amount of energy source purchased from the national energy market;

NB_m is the amount of commercially produced nitrogen, pound, purchased for the endogenous crops in market region m; and

EN_n is the amount of energy required to produce a pound of nitrogen fertilizer.

Tillage practice restraints In each market region one restraint is defined to control the proportion of reduced tillage acreages to the total cultivated acreages. This restraint reflects the time lag involved in changing farming practices. The time lag is due mainly to the learning process which has to take place before more farmers adopt reduced tillage practices and to the replacement time of farm machinery.

If no other circumstances prevail, such as a changing energy situation or increased soil erosion, the proportion of reduced tillage acreage in each region by 1985 is assumed to increase by 24 percent from the 1974-1975 average (Table 3.1). However, an energy shortage as well as high energy prices would encourage farmers to increase adoption of reduced tillage methods. The tillage practice restraints interact with a set of tillage practice activities to simulate the increased adoption of reduced tillage, and to determine the desired proportion of reduced tillage acreages in each of the alternatives.

Restraints at the national level

Two restraints are defined at the national level to control the national supplies and demands for cotton and sugar beets. The crop activities producing these commodities in each producing area are capable of supplying these commodities directly into the national market restraints. In other words, no transportation activities are defined for these commodities [29].

Five energy restraints (one for each energy source) are also defined at the national level. These restraints (rows 00 in Figure 3.4) act as the national energy markets. The energy in each of the national energy markets is obtained from national energy buying activities (columns 00 in Figure 3.4).

Activities

Activities serve as a mechanism whereby production alternatives, commodity utilization, and transfer systems are incorporated into the

Table 3.1. Percentage of reduced tillage acres to total cultivated acres, 1974-1975 average and projected in 1985 by market regions

Market Region	1974-1975 Average[a]	Projected 1985
1	8.51	10.55
2	39.10	48.48
3	35.79	44.38
4	26.71	33.12
5	5.17	6.41
6	3.26	4.04
7	13.87	17.20
8	24.88	30.85
9	36.84	45.68
10	11.01	13.65
11	9.95	12.34
12	18.12	22.47
13	28.36	35.17
14	9.45	11.72
15	22.53	27.94
16	3.95	4.90
17	34.90	43.28
18	24.49	30.37
19	6.99	8.67
20	5.27	6.53
21	26.77	33.20
22	8.32	10.32
23	4.66	5.78
24	18.16	22.52
25	22.29	27.64
26	25.27	31.33
27	40.10	49.72
28	44.07	54.65
U.S. Total	18.72	23.21

[a]Source: Lessiter [28].

model. Basically, there are three classes of activities in the model: (1) crop production activities; (2) commodity transportation activities; and (3) resource supply activities, including water, nitrogen, and energy supply activities.

Crop production activities

The crop production variables or activities simulate the rotations producing barley, corn grain, corn silage, cotton, legume and nonlegume hay, oats, sorghum grain, sorghum silage, soybeans, sugar beets, and wheat. The crop production activities represent crop management systems incorporating rotations of one to four crops covering from one to eight years. Each rotation is defined as conventional or reduced tillage. Rotations producing corn and sorghum silage are defined only as conventional tillage residue removed. Rotations producing grain, cotton, and sugar beets can be defined as conventional tillage and reduced tillage. Therefore, a maximum of three different conservation practices can be defined for each rotation.

Two levels of fertilizer applications are assumed in defining crop activities. The first level assumes farmers apply the optimum amount of fertilizers. The optimum amount is derived from equating fertilizer costs with the marginal value of an addition unit of the commodity produced. The second level assumes farmers can only apply two-thirds of the above optimum level, an event that might happen under a fertilizer shortage. Combining the three tillage practices and the two fertilizer levels yields a maximum of six different ways to define a crop activity. These different ways of crop production are referred to as the six levels of fertilizer-tillage practices.

The derivation of energy use by crop coefficients is detailed in Appendix A. For derivation of other crop activity coefficients, see Nicol and Heady [32].

Commodity transportation

Transportation routes are defined between each pair of contiguous market regions. The model is basically one of partial transshipment. However, some heavily used long haul routes between noncontiguous market regions also exist, and transportation routes are defined to represent the long haul routes if the route reduced the mileage by 10 percent over the accumulated short haul routes [29]. Over each route two activities are defined for each commodity--one activity for shipment in each direction. Commodity transportation activities are defined for the following crops: barley, corn, oats, sorghum, oilmeal, and wheat.

Transportation costs To simplify the derivation of transportation costs, all grains and soybean products are assumed to be moved by railroads as the majority of the long hauls (200 miles and more) of grains are done by railroads, [16]. The costs of grain and soybean transportation, cents per ton-mile, are given in the 1972 Carload Waybill Statistics [19]. These costs vary according to the five railroad territories and the direction of the shipments.

Energy for transportation The energy requirements for transportation are greatly dependent upon the transportation mode. For the purpose of deriving the energy need in transportation coefficients, it is assumed that all grains are moved by railroads and one gallon of diesel fuel is required for every 235 ton-miles of shipment [16].

Resource supply activities

Water constraints have three components: downstream flows, interbasin flows, and water-buy activities. The downstream flows are bounded to a maximum of 75 percent of the available water upstream. The interbasin flows are bounded to a maximum of the water transfer system's capacity. Water-buy activities are bounded by the maximum available water supply in each water supply region (producing areas 48-105) as defined in Nicol and Heady [32] and Colette [5].

Commercially produced nitrogen-buy activities are not restrained and are defined in each of the market regions with the 1972 normalized nitrogen prices. These prices also reflect the historic regional nitrogen fertilizer price differences. The commercial nitrogen-buy activities supply nitrogen and consume natural gas and electricity for nitrogen production (see Appendix C for energy consumed for fertilizer production).

In each market region a livestock by-product activity allows the transfer of the nitrogen produced by livestock for use by crops. The amount of livestock by-products available in terms of N equivalents is determined from the number of livestock in each region. The prices of nitrogen obtained from livestock by-products are set to equal regional commercial nitrogen prices (since commercial nitrogen is the closest substitute to livestock by-products and thus under free markets represents the opportunity social costs for nitrogen produced by livestock). It is also assumed that no additional energy, except that used by livestock, is needed to make the nitrogen from livestock by-products available to the crops.

Five energy-buy activities are defined in each market region (Figure 3.4). These activities control the regional supply of diesel fuel (DSLB in gallons), natural gas (NGAS in 1000 cubic-feet), liquid petroleum gas (LPGB in gallons), electricity (ELCB in KWH), and a total energy supply (CALB in 1000 KCAL). The activities transfer energy from the national energy markets to the regional energy market rows. Five additional activities allow for the control of the total amount of energy consumed in agricultural production. The 1974 national and regional energy prices (Appendix D) for diesel fuel, LPG and electricity are determined from [39, 40, 41]. The price of natural gas is based on the 1974 state industrial natural gas prices [1]. The use of 1974 energy prices rather than 1972 prices is done to reflect the fact that energy prices have risen substantially more than other input prices since 1972. For example, between 1972 and 1974 fuel prices (gasoline and diesel) have more than doubled while the index of prices paid by farmers has risen by about 40 percent [42]. Thus, using 1972 energy prices would greatly underestimate the relative price of energy to other inputs clearly, cheap energy is a thing of the past.

Land Base

A major factor limiting production in agriculture is the availability of cropland. The total cropland acreage available in each producing area is determined from the Soil Conservation Service [6]. An adjustment is made for projected changes in exogenous land uses and irrigation development in 1985 (Table 3.2).

Table 3.2. U.S. land base acreages in 1985[a]

Item	OBERS E' 1985
	1000 Acres
Dry cropland available for endogenous crops	336,690
Irrigated cropland available for endogenous crops	32,874
Total cropland available for endogenous crops	369,564
Land used by exogenous crops	23,662
Land used for pasture and nonrotation hay	941,835
Total cultivated land	1,335,061

[a]Source: U.S. Water Resources Council [49].

Commodity Demands

The demands for all commodities in the study are exogenously determined. Final commodity demands include the population level, per capita demands (Table 3.3), net exports (Table 3.4), and livestock demands (Table 3.5)

Table 3.3. Projected national per capita commodity demands in 1985

Commodity	Units	OBERS E' Projection[a]
Barley	bushel	.0420
Corn grain	bushel	1.2070
Oats	bushel	.2120
Sorghum	bushel	.0000
Wheat	bushel	2.4720
Oilmeal	CWT	-.0865[b]
Cotton	bales	.0290
Sugar beets	tons	.1440
Beef and veal	pound	136.7000
Milk and milk products	pound	511.4000
Pork	pound	68.1000
Lamb and mutton	pound	1.8000
Turkey	pound	10.9000
Broilers	pound	44.8600
Eggs	dozen	42.6000

[a]Sources: U.S. Water Resources Council [49].

[b]Negative oilmeal consumption reflects an adjustment for the high protein grain by-products provided from the milling of the other grains.

Table 3.4. OBERS E' projected grain export in 1985 [a]

Commodity	Unit	Normal exports	High exports
		Million Units	
Barley	bushels	20.0	25.00
Corn grain	bushels	989.0	1,889.00
Oats	bushels	10.0	19.00
Sorghum grain	bushels	160.0	270.00
Wheat	bushels	775.0	1,179.00
Soybeans	bushels	950.0	1,125.00
Cotton	bales	4.1	4.21

[a]Source: U.S. Water Resources Council [49]

Table 3.5. Feed demands by livestock production under "normal" and "high" exports in 1985

Item	Unit	"Normal" Exports	"High" Exports
Corn	1000 bu.	4,287,724	4,186,321
Sorghum	1000 bu.	871,117	1,092,873
Barley	1000 bu.	840,011	913,768
Oats	1000 bu.	851,510	903,549
Wheat	1000 bu.	277,504	469,744
Oilmeals	1000 CWT	591,906	522,484
Legume hay	1000 tons	127,410	152,142
Nonlegume hay	1000 tons	211,535	221,531
Silage	1000 tons	125,709	74,113

as their major components. The study assumes a U.S. population of 233.2 million by 1985 with population distributed according to the OBERS E' projections [49].

Alternatives Evaluated and Their Assumptions

Five different alternatives (models) are evaluated. These are: base run (Model A), energy minimization (Model B), energy cut (Model C), high energy prices (Model D), and high exports, (Model E). All the alternatives assume the same U.S. population. All models, except the energy minimization alternative (Model B), are solved under cost minimization. Except for the high exports alternative (Model E), exports are the same for all models (Table 3.4). Hence, for the first four alternatives, the commodity demand vectors are identical. This is the reason for the identical national production levels in Models A, B, C, and D. Regional production, however, can vary among the alternatives because a transportation network is available to allow one region's demands to be fulfilled with imports from other regions. Livestock demands for feed grains and roughages are predetermined and are also identical for models A, B, C, and D. Cost of production, transportation, and other input costs are in terms of 1972 prices. As pointed out earlier, energy prices have been adjusted to reflect the relative changes in energy prices to other input prices between 1972 and 1974 (Appendix D).

The base run (Model A) is the control alternative. It is used for comparison with all the other alternatives examined in the study. Model A represents "a normal" long-run adjustment of agricultural production when no restrictions are imposed on the availability of energy, and energy prices remained at their 1974 levels (Appendix D).

Under energy minimization (Model B), the overall energy used in agricultural production (measured in 1000 KCAL) for field operations, irrigation, drying, transportation, fertilizers, and pesticides is minimized subject to the identical demands and other restraints used in the base run. This alternative (Model B), therefore, represents the maximum achievement in terms of energy saving which might take place in agricultural production regardless of the cost involved.

A somewhat similar situation, but one which minimizes the cost of food and fibers, exists under the 10-percent energy cut alternative (Model C). Under Model C, the amount of energy available to agricultural production (in 1000 KCAL) is restricted to only 90 percent of the base run.

The very likely situation of high energy prices in the future is analyzed in Model D. Under the high energy price alternative the cost of 1000 KCAL is assumed to be twice the base run energy cost. In the base run (Model A), the 1974 cost of 1000 KCAL is .858 cents per 1000 KCAL. Hence, under high energy prices (Model D) the cost of energy is assumed to be 1.716 cents per 1000 KCAL. This is equivalent to diesel fuel at 68.3 cents per gallon and electricity at 4.58 cents per KWH.

The high exports alternative (Model E) retains the same high energy prices but assumes exports will increase substantially by 1985 (Table 3.4).

The above five alternatives basically are benchmarks for analyzing different energy situations and their possible impacts on agricultural production. These situations can also be viewed as simulating alternative agricultural and energy policies such as all-out energy saving, energy reduction, increased energy prices, and all-out production to satisfy the growing world demands when accompanied by high energy prices.

IV. FOOD COSTS, FARM INCOME AND THE ENERGY CRISIS

Energy costs make up a small part of the final food costs. Even if we add the cost of indirect energy, such as energy for fertilizers, pesticides, etc., energy price changes still would have only a small impact on food costs. Therefore, if the only characteristics of the energy crisis has been increased energy prices then we should expect somewhat higher food prices in the future, but only minor changes in production methods and output levels. Of course, a substantial energy price increase will encourage farmers to reevaluate their input mix and to substitute other resources for energy. A more important characteristic of the energy crisis, however, has been an energy shortage. If energy prices could be adjusted immediately to reflect an energy shortage, then after a short time, no energy shortage would exist.[1] It is a well known fact that current energy prices are not necessarily equilibrium prices. Hence, it is quite possible that for a given set of energy prices, energy demands are greater than energy supplies. In other words, we have an energy shortage. The best example of this situation happened during the Arab oil embargo (October-December 1973).

The following analysis of the energy crisis and agricultural production is conducted under both situations, i.e., an energy shortage and high energy prices. The purpose of this chapter is to evaluate the impact of these energy situations and the impact of high agricultural exports on food costs and farm income. The impact of an energy shortage is evaluated under the 10 percent energy reduction alternative (Model C); high energy prices are evaluated in Model D; and the impact of high

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[1]An energy shortage can be defined as the difference between the quantity of energy demand and supply at a given energy price. If the energy demand curve slopes downward, the energy supply curve slopes upward then an energy shortage exists only below the equilibrium energy price. Therefore, an increase in energy price must bring energy quantity demand closer together with the energy supply; and at the equilibrium energy price, an energy shortage is completely eliminated.

agricultural exports accompanied by high energy prices are evaluated in Model E. All of the above alternatives are compared with the base run (Model A) in which no energy shortage is assumed to exist, energy prices remain at their 1974 levels, and agricultural exports remain "normal."

Impacts on Food Costs

An energy shortage as well as high energy prices are expected to increase food costs. The increase in food costs, in general, depends on the magnitude of the energy shortage and on the relative changes in energy prices. Of course, as the energy supply declines, some reductions in agricultural output can be expected. However, because of the complete inelastic commodity demands imposed by the nature of the analysis, the most noticeable impacts are increased commodity prices. The assumption of complete inelastic demands used in the study can be defended by noticing the relative inelastic domestic food demands. Domestic food demands would decline relatively much less than the percent increase in food prices. The elasticity of foreign food demands with respect to U.S. commodity prices is larger than domestic food demand elasticity. Other food exporters might capture an increasing share of the international food market when the cost of U.S. produced food is increased. The possibility of the United States losing much of the export food market, because of increased energy prices, however, is quite small since most of the food exporting countries face an energy situation similar to that of the United States. Therefore, an energy crisis, as 1973-1974 clearly showed, is a worldwide phenonomenon affecting all food producers and not just the United States.

The impact of the 10-percent energy reduction is clearly much greater than the doubling of energy prices (Table 4.1). On the average, raw commodity prices increase 13 percent because of doubling energy prices (Model D).[1] But, a 10 percent energy shortage or reduction leads to a 55 percent jump in raw commodity prices. The commodity prices reported here (Table 4.1) are not equilibrium market prices (retail prices). The prices obtained are shadow prices (supply prices) reflecting both long-run changes in agricultural production and the marginal cost of producing an additional unit of each commodity. It should not be assumed, therefore, that the increase in commodity supply prices are immediately transferred to the consumers.

The possible increase in retail food costs can not be directly imputed from Table 4.1. Most of the marketing processes such as transportation, freezing, canning, etc. are, however, much more energy intensive[2] than onfarm production. For example, ERS [16] shows that although fuel cost is only 8 percent of the total onfarm grain production costs, fuel cost accounts for 24 percent of the processing and distribution costs for grain. If the energy crisis is not limited to onfarm production, as it can be safely assumed, then retail food cost increases would be at least as large or larger than indicated in Table 4.1. By the same reasoning, it can be concluded that other commodity (livestock, fruit and vegetable) prices might also increase sharply under

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[1]This is a much larger increase in food costs than the increase obtained by ERS [16] because some indirect energy, such as energy for fertilizers and pesticides, is also included.

[2]Energy intensity can be defined as the proportion of energy costs of the total processing costs.

an energy shortage. The production processes of these commodities, in general, are more energy-intensive than grain products. Vegetable prices, for example, under an energy crisis might increase more than any of the other commodities because most of the vegetable acreages are irrigated, and large proportions of vegetable acres are grown in the Southwest (California, Arizona, and New Mexico) where irrigation is, in general, a very energy-intensive process.

An energy shortage as well as high energy prices change the relative price of commodities. For example, the average commodity price increases by 55 percent under the 10 percent energy reduction. However, corn grain, sorghum grain, soybeans, and hay prices increase more than 65 percent. Thus, an energy crisis is not expected to increase all commodity prices by the same proportion. Under an energy shortage or high energy prices, increased relative prices for corn grain, sorghum grain, soybeans, and hay are indicated (Table 4.2). On the other hand,

Table 4.2. Relative commodity price changes under different alternatives in 1985

Commodity	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
Corn grain	100,000	N.A.	106.60	101.07	106.76
Sorghum grain	100,000	N.A.	114.93	105.57	125.37
Barley	100,000	N.A.	91.82	97.75	101.82
Oats	100,000	N.A.	90.10	95.41	123.98
Wheat	100,000	N.A.	96.31	100.43	131.40
Soybeans	100,000	N.A.	109.32	104.48	109.70
Hay	100,000	N.A.	107.05	102.96	87.91
Silage	100,000	N.A.	97.46	99.76	87.78
Cotton	100,000	N.A.	98.70	98.66	70.22
Sugar beets	100,000	N.A.	91.27	95.45	61.76
Average	100,000	N.A.	100.00	100.00	100.00

the relative prices of small grains (barley, oats, and wheat), silage, cotton, and sugar beets decline. In part, these relative price changes can be explained by the higher energy intensiveness (compared with the small grain crops) of the row crops, especially corn grain, sorghum grain, and soybeans (see Chapter VI, Table 6.1). Also, irrigation is a more important input in growing row crops than in growing small grains. Cotton relative prices decline only slightly because much of the irrigated cotton is shifted to dryland production under an energy shortage.

The above price changes would, undoubtedly, alter the output mix of agricultural products. Livestock producers, for example, would substitute more small grains for corn and sorghum. We should also expect some silage to be substituted for hay as the relative price of hay increases more than silage. Such a commodity substitution when involving legume hay might be very limited as less legume hay implies less nitrogen carry-over. The preceding crops, therefore, have to substitute a highly energy intensive input, commercially produced nitrogen, for the nitrogen left over after the legume hay.

The impact of an energy reduction on food costs has some important implications for energy conservation policies. First, it must be realized that there is a trade-off between food costs and energy used in agriculture. At least as far as agriculture is concerned, there is no such thing as free energy saving. Of course, energy saving based on elimination of energy waste should be encouraged. But, any energy waste in agricultural production must be quite small, because increased energy prices in the last few years have encouraged farmers to improve energy use and illiminate most of their wasted energy.[1] In general, energy saving in agriculture requires changes in farming methods, resource substitution, and regional reallocation of production. If we accept the unlimited energy situation (Model A of the analysis) as an optimal unrestricted energy solution, then any energy reduction, achieved either by an energy restriction or by high energy prices, would result in higher food costs. Increased food costs because of an energy reduction, however, must not be used to promote all-out energy for agriculture. Instead, any energy reduction policy affecting agriculture also should consider the impact on food costs.

Studies of energy and agriculture should take into consideration food cost impacts. Therefore, introducing new or old technology that might reduce energy use in agriculture should be accompanied by an analysis of the impact on food costs. For example, many authors suggest that under an energy crisis, we should reconsider the substitution of labor for energy, especially when the economy is not at full employment. However, farmers operating under a competitive market structure are profit maximizers. Any method resulting in higher production costs, such as increased labor, would most likely be rejected by farmers. To adopt an energy-saving method, farmers as well as other businessmen must be inspired by economic incentives.

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[1]The competitative nature of farming and the fact that farmers are unable to pass the additional cost of energy to the consumer occurs because each one of them has very little influence over commodity prices which tend to support such a conclusion.

Farm Income Effects

An energy shortage and high energy prices have an important impact on farm income and on the regional distribution of income from farming. Whether farmers are better off under an energy crisis depends, in part, on agricultural exports and the increase in input prices because of higher energy prices. In general, the inelastic demand for agricultural commodities implies that higher commodity prices would increase farm income. However, if input prices increased substantially, and farmers cannot pass these additional costs to the consumers (commodity prices would not increase enough to cover both direct and indirect energy cost increases), then farmers would be worse off under an energy crisis. Although this kind of cost squeeze (because of high energy prices) is possible, it does not seem probable. High energy prices would reduce irrigated acres and would cut down nitrogen application. Both factors are expected to affect crop yields and, therefore, agricultural output. Foreign demands for U.S. agricultural products might be even higher under an energy crisis. This outcome might exist if foreign production of agricultural commodities was severely curtailed because of a reduction of energy and fertilizers. Thus, it is reasonable that U.S. farm income would increase under a world energy shortage and high energy prices. Clearly, such an income increase is not distributed equally among regions. Western irrigated regions would be relatively worse off than eastern and midwestern regions.

For the purpose of this study, farm income is defined as the total return to land, labor, and water resources evaluated at their opportunity costs (shadow or supply prices). Clearly, farmers do not retain all the return to resources as many use hired labor, buy water, and lease land. However, such a definition is very useful for a national agricultural policy model as it includes the total returns to labor owners, water owners, and landowners. The complete inelastic commodity demands used in the first four alternatives (Models A, B,[1] C, and D), cause total farm income changes (Table 4.3) to be closely related to commodity price changes (Table 4.1). But large regional differences exist under each of the alternatives. Under the 10-percent energy shortage (Model C), dryland farming regions increase their farm income much more than irrigated regions. For example, the South Atlantic region almost doubles its farm income under the 10 percent energy shortage. But, farm income in the Northwest region declines slightly (Table 4.3). Furthermore, the more likely situation of high energy prices results in declining farm income for three regions--South Central, Southwest, and Northwest. At the same time, the South Atlantic and the North Central regions increase farm income by 27 and 14 percent, respectively (Table 4.3). High exports, of course, would increase farm income to all regions, but it is especially important to irrigated regions as these regions' farm income then increases substantially above the base run (Table 4.3). For example, under high exports (Model E), farm income in the Northwest region increases more than sixfold over the base run.

Changes in regional farm incomes under an energy crisis are basically

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[1]Farm income under Model B is not available because commodity prices are in terms of KCAL. Therefore, it is incomparable with income under other alternatives.

Table 4.3. Regional farm income[a] under different alternatives in 1985

	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			(1,000 dollars)		
North Atlantic	429,485	N.A.	641,306	476,283	1,549,355
South Atlantic	1,268,799	N.A.	2,533,197	1,609,653	5,321,224
North Central	4,264,350	N.A.	7,379,139	4,863,385	19,243,254
South Central	848,119	N.A.	887,321	836,972	5,398,709
Great Plains	1,485,981	N.A.	2,044,852	1,626,299	7,356,161
Northwest	207,673	N.A.	191,264	170,285	1,530,603
Southwest	586,006	N.A.	598,918	552,831	1,415,792
United States	9,090,413	N.A.	14,276,029	10,135,402	41,815,098
		Changes from Model A			
North Atlantic	100.00	N.A.	149.32	110.90	360.75
South Atlantic	100.00	N.A.	199.65	126.86	419.39
North Central	100.00	N.A.	173.04	114.05	451.26
South Central	100.00	N.A.	104.62	98.69	636.55
Great Plains	100.00	N.A.	137.61	109.44	495.04
Northwest	100.00	N.A.	92.10	82.00	737.03
Southwest	100.00	N.A.	102.20	94.34	241.60
United States	100.00	N.A.	157.05	114.50	459.99

[a]Farm income is defined as the total return to land, water, and labor.

a reflection of changing relative regional advantages in favor of dryland farming. Such long-run changes would improve the relative income position of eastern and midwestern regions. For some crops, these changes could be extremely important. For example, the past trend of cotton shifting from the South Atlantic region to the Southwest might even be reversed. Under an energy shortage or high energy prices, irrigated cotton farming is a relatively expensive cotton production method. Under the high energy price alternative (Model D), the production of one bale of cotton requires (on the average) 1.6 million KCAL as dryland and 2.9 million KCAL as irrigated cotton (see chapter VI Table 6.1). This difference (mostly because of irrigation) is worth $11 in 1974 energy prices. In some western regions where irrigation is a very energy intensive process, irrigated cotton requires even more energy than indicated above. As explained later, the new regional distribution of agricultural production, because of the energy crisis, would have additional impacts on the agribusiness sector, rural communities, and the environment.

The study does not deal directly with the impact of the energy crisis on rural communities or the agribusiness sector. However, some possible impacts should be noted. Rural community income is closely related to farm income. Therefore, it can be concluded that increased farm income in the dryland farming regions because of an energy shortage would have a positive impact on the rural communities in those regions. What would happen to rural communities in the West depends upon the impact of the energy crisis on irrigated farming in western irrigated regions. As shown earlier, those impacts might be greatly different under different export levels. Undoubtedly, low agricultural exports accompanied by an energy shortage would spell hardship to many western communities.

The impact of the energy crisis on the agribusiness sector depends on the specific service performed by the agribusiness firm. Fertilizer dealers would face declining sales as farmers reduce their commercial fertilizer application. Similarly, irrigation equipment manufacturers would face lower sales of new equipment as irrigated farming profitability would be reduced. Irrigated equipment manufacturers should, however, anticipate increased demands for the type of irrigation equipment that requires less energy to operate. Demand for irrigation equipment, that improves irrigation efficiency (sprinklers for example), might also increase. Unfortunately, increased irrigation efficiency (i.e., reduced water application achieved by sprinkler irrigation) in many cases means lower energy efficiency in irrigation as sprinkler irrigation is relatively energy inefficient [2]. Solutions of restricted supplies and increased prices of energy show greater use of reduced tillage practices. Farm machinery dealers should expect to sell more reduced tillage equipment. High exports thus would be beneficial to both the farming sector as well as the agribusiness sector even under high energy prices.

Agricultural Exports Effects

Since 1973 the world economy has faced two severe shocks in agricultural products and in petroleum. Because both commodities are basic to the economic well-being of every country, shortages and dramatic price increases have had serious political ramifications. The current world's agricultural problems stem largely from adverse weather conditions and worldwide economic boom. In contrast, the energy crisis was caused by man. By a joint action, the major oil exporting countries have substantially raised crude oil prices and have been able to reap large monopolistic profits.

United States agriculture responded quickly to increased world food demands. Because of the larger U.S. productive capacity and the size of U.S. held grain stocks, U.S. agriculture was able to meet domestic food demands and still make a substantial contribution to meeting the expanded world food demand.

Despite the sharp increase in the value of energy imports (Figure 4.1), the United States had managed to substantially improve its balance of payments. The United States had a $10 billion deficit in 1970, a record $30 billion deficit in 1971, and again, a $10 billion deficit in 1972. However, it ended 1973 with a foreign trade surplus of more than $5 billion [8]. Agricultural exports led the way in improving the U.S. balance of payment situation. Although agricultural exports were only 25 percent of total U.S. exports in 1973, they accounted for nearly 40 percent of the export increases in that year [8]. Because of the strong demand for U.S. agricultural products, the value of U.S. agricultural exports tripled between 1970 and 1974 (Figure 4.1).

Hence, the U.S. economy benefits greatly from expanding agricultural exports. High agricultural exports increase employment both on and off the farm. The analysis of the high exports alternative (Model E), simulates a situation of high exports. The analysis assumes both high agricultural exports and high energy prices (twice the 1974 energy prices).

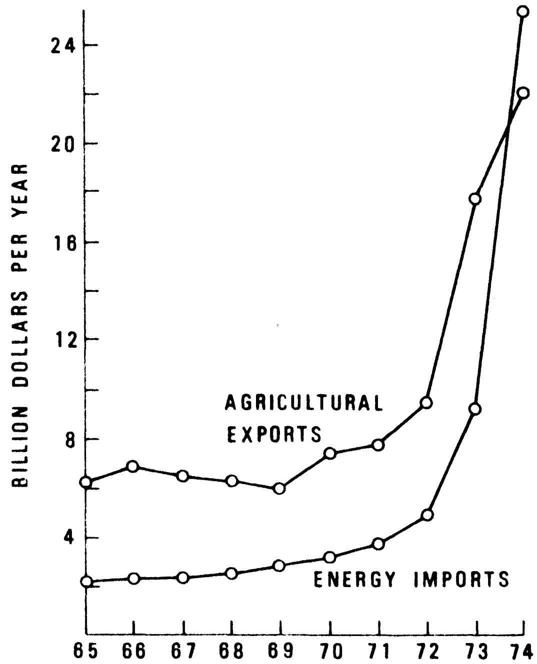

Figure 4.1. Agricultural exports[a] and energy imports[b] 1965-1974

[a]Source: USDA [44].

[b]Source: Bureau of the Census [47].

Under the high exports alternative (Model E), the value of agricultural exports increases by 229 percent (Table 4.4) from the base run (Model A). At the same time, energy consumption in agriculture increases by only 29 percent over the base run (Model A). Even if we assume that all that additional energy used must be imported at twice the 1974 energy prices, the high exports require an additional $4.0 billion per year spent on imported energy. The additional energy cost, however, is far less than the additional value of agricultural exports ($13.3 billion) under the high export alternative (Model E).

Summary and Implications

A major impact of an energy shortage and high energy prices is increased food costs. A 10 percent energy reduction to agricultural production would result in commodity prices increased by 55 percent. Doubling energy prices, on the other hand, will result in a 13 percent increase in commodity prices. An overall energy shortage for the U.S. food system might increase retail food prices even more than indicated above, as marketing and processing of raw commodities are more energy intensive than onfarm production. The energy crisis is expected to change the relative commodity prices such that row crop prices increase relatively more than small grain prices.

An important implication of the results thus far is the realization that there is a clear trade-off between energy use in agricultural production and food costs. The ability of agriculture to save energy without a noticeable change infood costs is quite limited. Significant energy-saving in agriculture can be achieved mainly by changing farming

Table 4.4. U.S. agricultural exports under different alternatives in 1985

Commodity	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			Million dollars		
Corn grain	930	N.A.	1,533	1,058	4,099
Sorghum grain	144	N.A.	256	171	659
Barley	24	N.A.	34	26	66
Oats	9	N.A.	13	10	48
Wheat	1,124	N.A.	1,674	1,271	4,858
Soybeans	3,012	N.A.	5,096	3,544	8,460
Cotton	533	N.A.	802	586	837
U.S. total	5,775	N.A.	9,404	6,667	19,025
			Changes from Model A		
Corn grain	100.00	N.A.	164.84	113.76	440.08
Sorghum grain	100.00	N.A.	177.78	118.75	457.64
Barley	100.00	N.A.	141.67	108.33	275.00
Oats	100.00	N.A.	144.44	111.11	533.33
Wheat	100.00	N.A.	148.93	113.08	432.21
Soybeans	100.00	N.A.	169.19	117.66	280.88
Cotton	100.00	N.A.	150.47	109.94	157.04
U.S. total	100.00	N.A.	162.84	115.45	329.44

methods and by regional reallocation of agricultural production. It is highly recommended that future studies on energy and agriculture should try to explain how the results might affect food costs. Suggesting that energy can be saved in agriculture without indicating the cost involved in doing so is not adequate for the current world problems. Measuring energy efficiency in agriculture by comparing fossil energy input with food energy output is not an adequate measurement as people value food not only for its calorie content but also for its taste and other nutrients. A typical example is dietetic food, which contains very few calories but is very costly.

The energy crisis is expected to change the regional farm income distribution. Dryland farming regions would increase their income share while the income share of irrigated farming regions would be reduced. Changing income distribution is mainly because of declining irrigated farming. An energy shortage will reduce yields, production, and therefore can be expected to assure high prices for farmers. A worldwide energy crisis could be an important reason for high agricultural exports.

High agricultural exports would require more energy, but would help substantially to improve U.S. balance of payments. For every dollar spent for energy, agriculture can return more than three dollars in exports even if energy prices rise to twice their 1974 levels. Increased agricultural exports would mean a better fed world and improved farm income.

V. ENERGY SHORTAGE, HIGH ENERGY PRICES AND RESOURCES USE IN AGRICULTURAL PRODUCTION

Not only has U.S. production responded quickly to technological changes, but also agriculture has managed to adjust its resource mix in line with the relative changes of input prices. For the last 30 years, the major shift in resource utilization has been toward more capital and less labor inputs. Most of the capital intensive technologies adopted by farmers were also energy-intensive technologies. Increased energy use, therefore, has been an important factor in increasing agricultural productivity in the United States.

It is often suggested that the changing world's energy situation might greatly reduce the ability of modern agriculture, such as U.S. agriculture, to increase production when energy supplies are dwindling and energy prices are rising rapidly. This study does not provide a complete answer to the above issue, but it analyzes some of the most important changes, some of which are already underway, in crop production because of an energy shortage and increasing energy prices. This chapter covers the long-run impacts of the energy crisis on resource use and substitution in the agricultural sector.

Energy Resources in Agricultural Production

Under the base run, by 1985 production of the endogenous crops, transportation of raw agricultural products, and direct inputs such as fertilizers and pesticides, require 5.4 billion gallons of diesel fuel, 180.1 billion cubic feed of natural gas, 657 million gallons of liquid petroleum gas (LPG), and 12 billion KWH of electricity (see Chapter I, Table 1.3). These energy resources sum up to 292.483 x 10^{12} KCAL (1,161 x 10^{12} BTU). By comparison, U.S. total energy consumption in 1972 [18] was 18,171 x 10^{12} KCAL (72,107.4 x 10^{12} BTU). Therefore, under the base run, energy consumption in agricultural production in 1985 would account for only 1.61 percent of the total U.S. energy consumption in 1972. In terms of specific energy sources, crop production requires about 2.3 percent of U.S. petroleum and electricity demands and less than 1 percent of the annual U.S. natural gas consumption.

These figures support the hypothesis that any energy saving in agricultural production will have a small effect on the total energy consumed in the United States. However, any energy reduction to agriculture, such as the 10 percent energy reduction examined under Model C, will have a severe impact on food costs (up 55 percent), and will do almost nothing toward reducing U.S. total energy consumption. The 10 percent energy reduction is only .2 percent of U.S. total energy consumption in 1972.

Energy consumed in agricultural production reaches its maximum under the high exports alternative (Model E). But even under high exports, energy consumed in agricultural production, (377.544 * 10^{12} KCAL, or 1,498 * 10^{12} BTU), would have been only 2.07 percent of U.S. total energy consumption in 1972. Increased fertilizer use (especially nitrogen) is expected to increase the share of natural gas in agricultural production when compared to the U.S. total, from less than 1 percent under the base run (Model A) to 1.84 percent under the high exports alternative (Model E).

Regional variations of energy consumed in agricultural production (Table 5.1) are mostly related to changes in irrigation as shown later.

Thus, the western regions (South Central, Southwest, and Northwest) show the largest reduction in energy use under an energy shortage. The Northwest region is very sensitive to both an energy shortage and high energy prices. Under high exports (Model E), all regions increase their energy needs, but the western regions increase energy use relatively more than the eastern regions, as much of the additional production for the high exports can only be obtained by a substantial increase in irrigated acres.

Table 5.1 has important implications for an energy allocation program which the government might use as a way of lessening energy consumption. Using the 10 percent overall energy reduction (Model C) to simulate an energy shortage, an optimal (e.g., least-cost) allocation of the scarce energy is derived by unequal regional energy reductions. For example, the 10 percent overall energy reduction is accompanied by a 34 percent energy reduction in the Northwest region and only a 5 percent energy reduction in the North Central region. Some regions might actually use more energy under an energy shortage than under a plentiful energy situation if we were to have a least-cost regional energy allocation. Thus, an optimum regional location of production is one way of obtaining energy savings at least cost.

Western regions, contributing the most toward energy saving as their crop patterns shift, lose relatively more of their farm income and thus are relatively worse-off than eastern regions which contribute less toward reduced energy use. Whether the cost and energy saving achieved by an optimal interregional allocation of energy is worth the hardship caused by a different income distribution pattern

Table 5.1. Regional energy use and changes from the base run (Model A) in 1985

Major Zone	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			10^{12} KCAL		
North Atlantic	7.468	6.799	6.742	7.132	8.415
South Atlantic	31.572	28.096	29.512	30.821	37.862
North Central	104.842	94.112	99.246	101.474	130.697
South Central	50.901	38.957	40.161	46.827	69.768
Great Plains	53.230	47.826	51.547	52.858	78.191
Northwest	15.076	10.504	9.901	10.965	20.123
Southwest	29.348	23.328	26.085	27.277	32.488
United States	292.438	249.622	263.194	277.353	377.544
			Changes from Model A		
North Atlantic	100.00	91.04	90.28	95.50	112.68
South Atlantic	100.00	88.99	93.48	97.62	119.92
North Central	100.00	89.77	94.66	96.79	124.66
South Central	100.00	76.53	78.90	92.00	137.07
Great Plains	100.00	89.85	96.84	99.30	146.89
Northwest	100.00	69.67	65.67	72.73	133.48
Southwest	100.00	79.49	88.88	92.94	110.70
United States	100.00	85.36	90.00	94.84	129.10

is a consideration which must be studied carefully.

The analysis of energy prices (Table 5.2) is based on the relationships between three different sets of energy prices, 1974 energy prices, energy shadow (supply) prices, and high energy prices. The 1974 energy prices reported in [1, 39, 40, 41] and applied to the base run (Model A), result in an average energy price of .858 cents per 1,000 KCAL. The energy shadow prices (opportunity prices), derived under the 10 percent energy cut (Model C), result in an average energy price of 3.505 cents per 1,000 KCAL. Under both the high energy price alternative (Model D) and the high export alternative (Model E), an average energy price at twice the 1974 levels, 1.716 cents per 1,000 KCAL is assumed. Conversion of these energy prices to the equivalent crude oil price (one barrel of crude oil = 1,461,600 KCAL) results in $12.54, $51.23, and $25.08 per barrel under the 1974 prices, energy shadow prices, and high energy prices, respectively.

The very high energy shadow prices, 3.505 cents per 1,000 KCAL, obtained under the 10 percent energy cut requires explanation. This energy price is the value of the last unit of energy to agricultural production when a 10 percent energy shortage exists. Or stated in another way, if agriculture could be supplied with another barrel of crude oil (or its fuel equivalent) under an energy shortage, then total commodity costs would be reduced by approximately $51.23.

The proportion of natural gas used under high exports (Model E) is considerably higher than for the other alternatives. This sharp increase is because of a greater use of commercially produced nitrogen

Table 5.2. National energy prices,[a] and proportional distribution of energy sources consumed in agricultural production in 1985

Energy Source	Unit	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
		Cents Per Unit				
Diesel fuel	gallon	35.614	N.A.	136.829	68.267	77.858
Natural gas	1,000 $feet^3$	62.554	N.A.	240.333	119.906	136.753
LPG	gallon	30.008	N.A.	115.291	57.521	65.602
Electricity	KWH	2.387	N.A.	9.171	4.576	5.218
Total	1,000 KCAL	.858	N.A.	3.505	1.716	1.716
		Energy Distribution				
Diesel fuel	percent	66.38	75.93	73.68	70.52	56.80
Natural gas	percent	16.95	12.43	13.08	15.21	29.08
LPG	percent	5.48	5.29	5.32	5.50	4.76
Electricity	percent	11.19	6.35	7.92	8.77	9.36
Total	percent	100.00	100.00	100.00	100.00	100.00

[a]Energy prices are based on 1974 prices.

and an increased irrigation in the western regions (Table 5.2). By comparison it is estimated that energy sources used in agriculture in 1970 were divided as 52.1 percent petroleum, 30.3 percent natural gas, 13.8 percent electricity, and coal and other 3.8 percent [16].

The distribution of energy use among farming operations is presented in Table 5.3 for the several models. Approximately two-thirds of the energy consumed is used for tractors, combines, and other self-propelled machinery. These operations thus have the greatest energy saving potential. Up to now, the most promising way to cut fuel consumption for field operations has been increased adoption of reduced tillage. For models involving high energy prices or energy restrictions, greater use of reduced tillage practices clearly takes place. Under energy minimization (Model B), fuel for machinery is reduced by about 3 percent. The proportion of reduced tillage increases from 39 percent in the base run (Model A) to 88 percent under the energy minimization alternative. The main reason for the overall small reduction in fuel use under the energy minimization alternative (Model B), is the sharp increase in land use (up by more than 13 million acres) and not the ineffectiveness of reduced tillage methods. On a per acre basis, reduced tillage contributes toward a 12 percent reduction in fuel use for dryland corn and a 19 percent reduction in fuel use for dryland sorghum (Appendix E). Reduced tillage acres under the energy minimization alternatives increase the amount of energy required for pesticides by more than 27 percent from the base run (Model A). Hence, increased energy for pesticides offset some of the energy saving achieved by reducing fuel for machinery.

Table 5.3 presents another phenomenon. An energy saving in agriculture might require more energy to be used by other sectors of the economy. The best example of this phenomenon is the sharp increase in energy use for transportation under the energy minimization alternative. Increased energy for transportation takes place as crop production shifts eastward, due to reductions of irrigated acres in the West. Commodity demands, however, depend on population distribution and export points. Therefore, more agricultural products must be shipped westward to satisfy the regional demands. This is an example why a piecemeal approach to energy saving in agriculture (and elsewhere) might lead to very little, if any, energy saving. Looking at the reductions of energy used for irrigation and nitrogen (Table 5.3, Model B) we might be led to conclude that a great energy saving has been achieved only to find out that to maintain output we must use more fuel for transportation and pesticides.

Land and Water Use

The abundance of land resources in the United States is the most important factor in making U.S. agriculture the world's largest food producer. Until recently, U.S. agricultural policy was oriented toward holding cropland out of production to reduce excess supplies. Since 1972, however, the sharp increase in agricultural exports led to removal of all set-aside, and other programs aimed at controlling production. The analysis of land and water use shows that these important natural resources can greatly help to eliminate the effect of reduced energy use on agricultural production. The increased use of cropland

Table 5.3. Energy use in crop production and percent distribution for different alternatives in 1985

Inputs	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			10^{12} KCAL		
Fuel for machinery	169.573	164.956	169.435	171.520	184.465
Pesticides	7.374	9.405	7.896	7.518	7.875
Nitrogen fertilizers[a]	36.455	11.969	26.904	31.363	95.563
Nonnitrogen fertilizers	7.207	7.287	7.036	7.060	8.019
Crop drying	13.056	12.148	12.610	12.933	14.320
Irrigation	41.456	.416	21.737	29.849	44.862
Transportation	17.317	43.441	17.576	17.110	22.440
Total	292.438	249.622	263.194	277.353	373.544
			Percent Distribution		
Fuel for machinery	57.99	66.07	64.38	61.84	48.86
Pesticides	2.52	3.77	3.00	2.71	2.09
Nitrogen fertilizers	12.47	4.79	10.22	11.31	25.31
Nonnitrogen fertilizers	2.46	2.92	2.67	2.55	2.12
Crop drying	4.46	4.87	4.79	4.66	3.79
Irrigation	14.18	.17	8.26	10.76	11.89
Transportation	5.92	17.41	6.68	6.17	5.94
Total	100.00	100.00	100.00	100.00	100.00

[a]Energy for nitrogen fertilizers indicates energy for commercial purchased nitrogen fertilizers only.

(Figure 5.1) is a major reason why agriculture can maintain production and exports under different energy situations. The energy-cropland substitution curve (Figure 5.1) connects four energy use levels derived under the base run, high energy prices, 10 percent energy cut, and energy minimization--Models A, B, C, and D, respectively. It shows that the same demand levels can be attained with various combinations of energy and land.

Regional land use changes (Table 5.4) are much greater than the national land use changes. This is especially true in the western regions where more dry cropland is needed to compensate for the reduction in irrigated cropland. For example, total cropland in the Northwest region increases about 13 percent under the 10 percent energy cut as irrigated farming declines drastically from the base run. High exports, analyzed in Model E, have much greater impact on land use than any of the alternatives analyzed. Under high exports, irrigated regions benefit since much of the additional production must come from irrigated land.

The severe impact of an energy crisis on irrigated farming in the West is demonstrated in Table 5.5. Two regions, South Central and Northwest are the hardest hit by an energy shortage. Under the 10 percent energy reduction (Model C), the South Central region (Texas, Oklahoma, and New Mexico) loses about two-thirds of its endogenous irrigated crops, most of which occurs on the High Plains of Texas. The Northwest region (Washington, Oregon, and Idaho) loses about 90 percent of its irrigated endogenous crops. This compares with a 41 percent overall irrigated acreage reduction under the 10 percent energy shortage (Model C). The impact of high energy prices (double their 1974

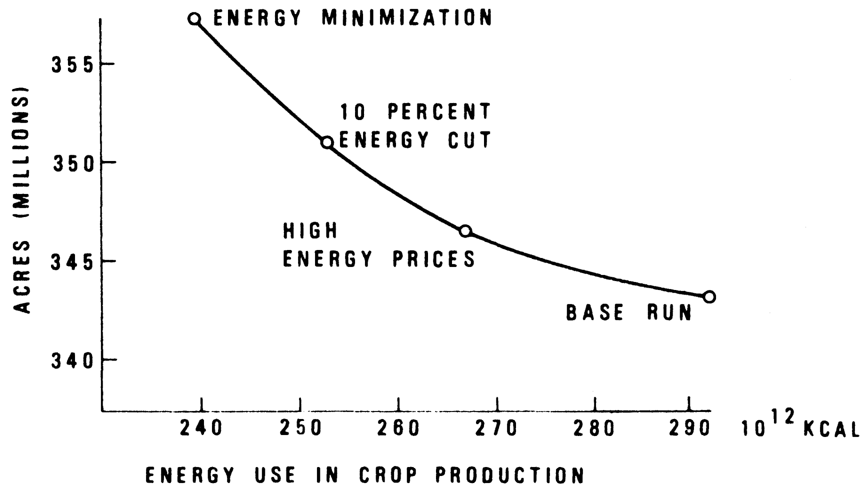

Figure 5.1. Energy-cropland substitution among different alternatives

Table 5.4. Total regional endogenous cropland use under different alternatives in 1985 [a]

Major Zone	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			1,000 Acres		
North Atlantic	11,420	11,373	11,382	11,431	11,473
South Atlantic	40,790	41,359	40,789	40,788	43,640
North Central	135,608	138,239	137,480	135,296	141,449
South Central	53,567	56,380	54,502	53,717	62,410
Great Plains	74,067	75,975	76,249	76,339	78,102
Northwest	11,677	14,357	13,166	13,085	15,154
Southwest	8,698	10,293	9,152	8,624	10,836
United States	335,825	347,974	342,717	339,278	363,062
			Changes from Model A		
North Atlantic	100.00	99.59	99.67	100.10	100.46
South Atlantic	100.00	101.39	100.00	100.00	106.99
North Central	100.00	101.94	101.38	99.77	104.31
South Central	100.00	105.25	101.75	100.28	116.51
Great Plains	100.00	102.58	102.95	103.07	105.45
Northwest	100.00	122.95	112.75	112.06	129.78
Southwest	100.00	118.34	105.22	99.15	124.58
United States	100.00	103.61	102.05	101.03	108.11

[a] Cropland use does not include summer fallow.

Table 5. 5. Irrigated endogenous cropland use under different alternatives in 1985

Major Zone	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			1,000 Acres		
North Central	138	0	138	138	138
South Central	5,665	1,098	1,928	4,849	7,166
Great Plains	6,331	3,850	5,314	5,326	8,502
Northwest	4,152	398	448	1,123	2,520
Southwest	6,608	4,276	5,668	6,469	7,290
United States	22,894	9,622	13,496	17,906	25,616
			Changes from Model A		
North Central	100.00	00.00	100.00	100.00	100.00
South Central	100.00	19.38	34.03	85.60	125.61
Great Plains	100.00	60.81	83.94	84.13	134.29
Northwest	100.00	9.59	10.79	27.05	60.69
Southwest	100.00	64.71	85.77	97.90	110.32
United States	100.00	42.03	58.95	78.21	111.89

levels) on irrigated acreages is smaller than the impact of the 10 percent energy shortage. Even then, the Northwest region remains worse off than other western regions. High exports (Model E) provide irrigated farming with an opportunity to increase production above the base run (Model A). But again, this is not true for the Northwest region. The great reduction of irrigated acres in the Northwest region under all alternatives results from the high energy intensity of irrigation in that region [12]. In addition, almost all the energy consumed by irrigation in the Northwest is electricity, the nation's most expensive energy source.

It is true that almost all the electricity in the Northwest comes from hydroelectric power plants. But at least some of that electricity can be transferred to nearby regions which use fossil fuel to generate electricity. For example, more than 70 percent of California's electricity came from fossil fuel in 1972 [9]. Therefore, from the national point of view, the opportunity cost of electricity in the Northwest region must be equated to the electricity cost from fossil fuel plants in the nearby regions. Also, growing electricity demands in the Northwest region might not be met by hydroelectric power, alone. Therefore, it is very likely that in the future much of the increased electricity demand in the Northwest region would be generated from fossil fuel. For that reason, it is assumed that the energy required to generate electricity in the United States reflects the conversion of all energy inputs (fossil fuel, nuclear, and hydroelectric) to electricity.[1]

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[1]In 1972 hydroelectric and nuclear power supplied less than 19 percent of total energy consumed by the United States as electricity. The same two energy resources accounted for less than 5 percent of the total energy consumed by the U.S. economy in 1972 [9].

The amount of water used for endogenous crops (Table 5.6), also reflects the impact of an energy crisis on irrigated agriculture. Under the 10 percent energy reduction (Model C), overall water consumption declines by 36 percent. Doubling energy prices (Model D) lead to a 22 percent reduction in water consumption. The decrease in water use because of an energy reduction (Figure 5.2) should be carefully interpreted. Although it is true that a substantial amount of energy can be saved in agriculture by reducing water use, it should not be concluded that the energy reductions obtained in the study can be achieved by the obtained levels of water use alone. The obtained energy reductions are achieved by adjustments in land use and cropping patterns, nitrogen fertilizer use, and regional shifts of production. Water reductions alone, other things unchanged, would have a much smaller impact on energy use than indicated in Figure 5.2.

Whether it is in the nation's best interest to promote further irrigation development in light of future energy shortages and uncertain export levels is a complicated issue. Even if regional development considerations are ignored, possibilities of high agricultural exports and drought conditions still prevail. Irrigation performs an important role in high exports (Table 5.6). Thus, high exports increase the relative competitiveness of irrigation which otherwise is disadvantaged under increased energy prices. The high exports alternative in this study and the increase in commodity prices since 1972 seem to indicate that irrigated farming can successfully compete with dryland farming in most regions even under high energy prices.

Table 5.6. Regional water consumption by endogenous crops under different alternatives in 1985

Major Zone	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			1,000 Acre-feet		
North Central	185	0	185	185	297
Great Plains	9,995	6,766	8,974	8,907	13,594
South Central	8,966	2,231	3,121	7,033	11,320
Northwest	9,313	889	968	2,416	6,148
Southwest	18,956	12,706	17,122	18,342	20,023
United States	47,421	22,598	30,377	36,890	51,389
			Changes from Model A		
North Central	100.00	00.00	100.00	100.00	160.54
Great Plains	100.00	67.69	89.78	89.11	136.01
South Central	100.00	24.88	34.81	78.44	126.25
Northwest	100.00	9.55	10.39	25.94	66.02
Southwest	100.00	67.03	90.32	96.76	105.63
United States	100.00	47.65	64.06	77.79	108.37

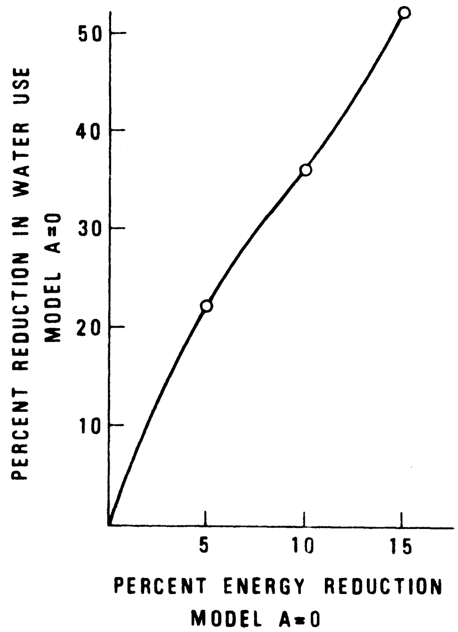

Figure 5.2. Effect of energy reduction on percentage reduction in water use

Nitrogen Fertilizers Use Under Limited Energy

The technological development and increased productivity of U.S. agriculture during the last 30 years has been marked by an ever increasing use of chemicals, especially inorganic fertilizers. The favorable capital-labor and capital-land price ratios and the high marginal productivities of the chemicals have encouraged individual farmers to use a greater amount of capital intensive inputs such as fertilizers, pesticides, and machinery. The increased use of these inputs has promoted increased crop yields and was a major reason for employment of government supply control programs during the 1952-72 period.

Recently, the world energy crisis has caused sharp increases in fertilizer prices and reduced fertilizer supplies. Of all fertilizers, nitrogen fertilizers are especially affected by the energy crisis because most nitrogen fertilizers are energy derived. For example, on the average, the production of a pound of nitrogen requires about 8,574 KCAL (Appendix C). This energy is equivalent to about a quarter gallon of diesel fuel. A farmer applying 100 pounds of nitrogen per acre uses energy equivalent to about 24 gallons of diesel fuel for nitrogen fertilizers alone. Nitrogen fertilizers, especially anhydrous ammonia, are heavily dependent on natural gas. On the average 38,000 cubic-feet of natural gas are required to produce a ton of anhydrous ammonia [50]. A declining natural gas supply, increased demand for natural gas by house heating, and possible future deregulation of natural gas prices may cut the supply of anhydrous ammonia even further and cause its price to increase.

Manure and other livestock by-products can be important sources of nutrients, especially nitrogen. Before the recent energy crisis, increased use of manure as a source of nutrients was encouraged mainly as a way to reduce feedlot water pollution. Recent standards imposed by the Environmental Protection Agency (EPA) call for strict control of water runoff from feedlots. The energy crisis provides further economic incentive for increasing manure utilization. This study assumes that all the manure produced by livestock and adjusted for normal feedlot losses (expressed as nitrogen equivalent), is available to be used by crops. It also assumes that use of livestock nitrogen does not require energy beyond that involved in livestock production and manure spreading. The cost of the nitrogen supplied by livestock is assumed to be equal to commercial nitrogen, the most closely available substitute. Thus, even under the base run (Model A), when no restrictions are imposed on energy supplies, and energy prices are at their 1974 levels, most of the manure available from livestock is utilized by crops.

Another source for nitrogen fertilizer is nitrogen carry-over from legume crops. Legume crops can convert a large amount of nitrogen from the air and deposit it in the soil. Legume hays provide carry-over for a two-year period after a good yielding stand. For the first year, the amount of nitrogen available for the following crops (pound per acre) is assumed to be

$$N_1 = 50.0 * Y - 5.0Y^2 + .2Y^3 \qquad (13)$$

For the second year, the amount of nitrogen available is assumed to be

$$N_2 = 81.5 - (81.5) * .8^Y \quad (14)$$

when N_1 and N_2 are the pounds of nitrogen per acre supplied by the legume hays for the crop following the first and the second year after plowing, respectively. And, Y represents the annual yield in tons of dry weight hay equivalent. A similar functional relationship has been developed for nitrogen carry-over from soybeans. Soybeans provide a carry-over of approximately one pound of nitrogen equivalent per bushel of soybean yield for the crop in the following year. For complete derivation of nitrogen carry-over see, Nicol and Heady [32].

The total nitrogen use (commercially produced, from legume crops carry-over, and from manure, Table 5.7) declines less than 5 percent from the base run under all the other energy alternatives analyzed. However, high exports (Model E) increase total nitrogen use by 57 percent from the base run (Model A). More revealing, however, is the distribution among commercial nitrogen use (Table 5.8), nitrogen carry-over (Table 5.9), and manure nitrogen utilization (Table 5.10). Commercial nitrogen use declines sharply as energy use declines. The 10 percent energy reduction (Model C) results in a 26 percent reduction in commercial nitrogen use. Doubling energy prices (Model D) results in a 14 percent reduction of commercial nitrogen use. However, high exports (Model E) cause a sharp increase in commercial nitrogen use (up 162 percent). This phenomenon, as shown earlier, is mainly because of the exhaustion of available cropland under the high export situation.

Table 5.7. Total nitrogen fertilizers used by crops under different alternatives in 1985

Major Zone	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			1,000 Tons of N		
North Atlantic	233	261	232	221	301
South Atlantic	631	526	567	588	921
North Central	2,814	2,672	2,747	2,715	4,135
South Central	1,110	1,037	1,018	1,057	1,844
Great Plains	1,424	1,416	1,417	1,437	2,420
Northwest	235	247	223	235	507
Southwest	296	279	266	267	426
United States	6,743	6,438	6,470	6,520	10,554
			Changes from Model A		
North Atlantic	100.00	112.02	99.57	94.85	129.18
South Atlantic	100.00	83.36	89.86	93.19	145.96
North Central	100.00	94.95	97.62	96.48	146.94
South Central	100.00	93.42	91.71	95.26	218.02
Great Plains	100.00	99.44	99.51	100.91	169.94
Northwest	100.00	105.11	94.89	100.00	215.75
Southwest	100.00	93.24	89.86	90.20	143.92
United States	100.00	95.48	95.95	96.69	156.52

Table 5.8. Commercial nitrogen purchased by crops under different alternatives in 1985

Major Zone	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			1,000 Tons of N		
North Atlantic	19	0	0	7	84
South Atlantic	313	191	222	269	496
North Central	824	558	629	700	2,123
South Central	258	141	151	195	864
Great Plains	390	209	294	361	1,314
Northwest	108	123	97	107	374
Southwest	214	174	176	190	318
United States	2,126	1,396	1,569	1,829	5,573
			Changes from Model A		
North Atlantic	100.00	0.00	0.00	36.84	442.11
South Atlantic	100.00	61.02	70.93	85.94	158.47
North Central	100.00	67.77	76.33	84.95	257.65
South Central	100.00	54.65	58.53	75.58	334.88
Great Plains	100.00	53.59	75.38	92.56	336.92
Northwest	100.00	113.89	89.81	99.07	346.30
Southwest	100.00	81.31	82.24	88.79	148.60
United States	100.00	65.66	73.80	86.03	262.14

Table 5.9. Nitrogen carry-over from legume crops under different alternatives in 1985

Major Zone	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			1,000 Tons of N Equivalent		
North Atlantic	78	120	94	77	92
South Atlantic	172	190	198	172	197
North Central	1,097	1,219	1,227	1,126	1,180
South Central	264	278	265	264	320
Great Plains	344	517	433	388	367
Northwest	74	71	73	75	67
Southwest	82	105	90	77	108
United States	2,111	2,500	2,380	2,179	2,331
			Changes from Model A		
North Atlantic	100.00	153.85	120.51	98.72	117.95
South Atlantic	100.00	110.47	115.12	100.00	114.53
North Central	100.00	111.12	111.85	102.64	107.57
South Central	100.00	105.30	100.38	100.00	121.21
Great Plains	100.00	150.29	125.87	112.79	106.69
Northwest	100.00	95.95	98.65	101.35	90.54
Southwest	100.00	128.05	109.76	93.90	131.71
United States	100.00	118.42	112.74	103.22	110.42

Table 5.10. Manure utilization by crops under different alternatives in 1985

Major Zone	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			1,000 Tons of N Equivalent		
North Atlantic	136	141	138	137	125
South Atlantic	146	145	147	147	228
North Central	893	895	891	889	832
South Central	588	618	602	598	660
Great Plains	690	690	690	688	739
Northwest	53	53	53	53	66
Southwest	0	0	0	0	0
United States	2,506	2,542	2,521	2,512	2,650
		Changes from Model A			
North Atlantic	100.00	103.68	101.47	100.74	91.91
South Atlantic	100.00	99.32	100.68	100.68	156.16
North Central	100.00	100.22	99.78	99.55	93.17
South Central	100.00	105.10	102.38	101.70	112.24
Great Plains	100.00	100.00	100.00	99.71	107.10
Northwest	100.00	100.00	100.00	100.00	100.00
Southwest	100.00	101.44	100.60	100.24	105.75
United States					

The importance of legume crops as a nitrogen source is clearly demonstrated in Figure 5.3. For every 2 percent reduction in commercial nitrogen purchased, nitrogen from legume crops increases approximately 1 percent. Hence, a fertilizer shortage caused by declining energy supplies can be offset partly by increased utilization of legume hays and soybeans in rotations. It should be mentioned, however, that the fixed commodity demands used in the analysis do not allow for much commodity substitution. The amount of nitrogen supplied from legume crops could be substantially larger if we allowed more legume hays to be substituted for other roughages (nonlegume hay and silage).

Some of the reduction in commercial nitrogen under an energy shortage is offset by an increase in the use of manure nitrogen (Figure 5.3). Increased manure utilization is very small as the number of livestock is fixed under the different energy situations. It should be emphasized that the larger reduction in commercial nitrogen use and the very small increase in manure utilization is because of the fact that almost all the manure available is utilized by the crops under the base run. This allows only minor adjustments to take place under the energy shortage. Clearly, if the base run analysis reflects the current rate of manure utilization, then an energy shortage, as well as high energy prices, would have a much greater impact on manure utilization than obtained in this study.

Summary and Implications

Resources substitution in agricultural production is the most important way for agricultural production to cope with the impact of an

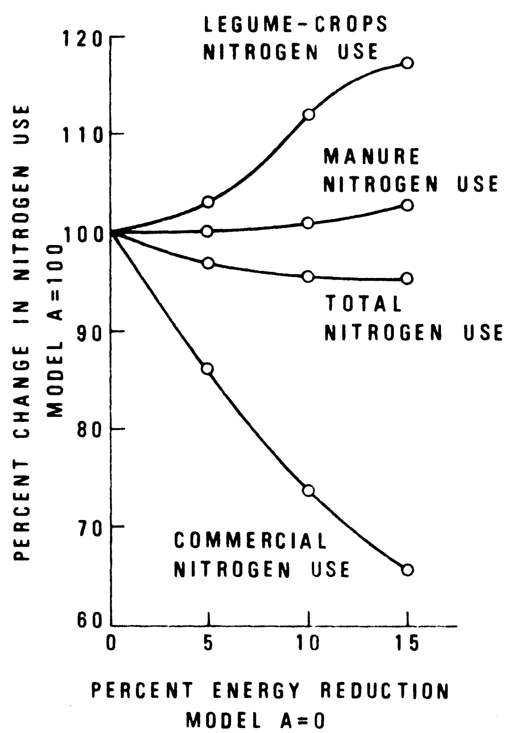

Figure 5.3. Changes in nitrogen use as a function of energy shortage

energy shortage and high energy prices. Unused cropland in the United States is not only a source of increasing agricultural productivity, but can be substituted for energy in agricultural production. Water and energy resources, however, are complementary resources. Therefore, less energy to agricultural production means decreased water use in the long run.

The benefit of energy saving in agricultural production to the rest of the economy is very small as agricultural production requires less than 2 percent of the annual U.S. energy use. But an energy reduction to agriculture would have a substantial impact on the location of agricultural production as well as on food costs. An equal regional energy reduction in agriculture is economically inefficient, even though it might be politically feasible. The most economically efficient regional energy allocation pattern would be achieved by irrigated farming regions reducing energy use more than dryland farming regions. Administering an unequal regional energy allocation might be politically unworkable. Moreover, it is an extremely expensive method for allocating scarce resources. It seems desirable, therefore, to let the market system allocate the scarce energy by adjusting energy prices to reflect energy scarcity.

Approximately two-thirds of the energy consumed in agricultural production annually is used as fuel for machinery. Irrigation uses about one-seventh and nitrogen fertilizers about one-eighth of the total energy consumed in agricultural production. Energy savings achieved by reduction of one input energy use might lead to a very small overall energy saving as more energy might be required for other inputs. Therefore, a piecemeal energy savings in agricultural production might have very little impact on the total energy use in agriculture.

A long-run energy shortage would drastically reduce irrigated acres and would shift agricultural production to dryland crops. High energy prices would severely reduce the competitiveness of irrigated farming. The South Central and the Northwest regions are the hardest hit by both an energy shortage and high energy prices. Irrigation farming would be much better off if high exports are possible. Rising energy prices without a large increase of agricultural exports would result in a severe cost squeeze, first to be felt by western irrigated regions.

Nitrogen fertilizers are supplied from commercial nitrogen purchased, carry-over from legume crops, and manure utilization. Commercial nitrogen is a petrochemical product, most of which is produced from natural gas, the most scarce energy source. The use of commercial nitrogen would decline sharply in response to an energy shortage and high energy prices. Most of the reductions in commercial nitrogen supplies could be replaced by increased utilization of manure and the nitrogen carry-over from legume crops, such that overall nitrogen use in agriculture might not greatly be affected. High exports, however, would require substantially more commercially produced nitrogen to increase yields and for the increased crop acreages. In summary, under "normal exports" there is great flexibility within agricultural production to replace commercially produced nitrogen with nitrogen from organic sources.

VI. FARMING PRACTICES, ENVIRONMENTAL QUALITY, AND THE ENERGY CRISIS

The recognition that environmental quality and energy use are closely related has gained considerable attention in the last few years. In most cases, energy use is related to environmental quality through industrial and service activities which consume energy and other natural resources and produce goods, services, and pollution. Air pollution is probably the most noticeable environmental product of increased energy use in the United States. The link between energy use and environmental quality in agriculture is not as direct as in other industries. Agricultural pollution is mainly related to the level of agricultural production. Soil loss, fertilizer runoff, and feedlot residue increase substantially as more crops and livestock products are produced. Changing farming practices, however, can allow for an increase in agricultural productivity such that total output is increased and environmental quality is not reduced.

The relationships between agricultural output, agricultural exports, and the environment are discussed in Center for Agricultural and Rural Development (CARD) studies such as Nicol, Heady, and Madsen [33]. The purpose of this chapter is to expand on the issue of environmental quality, especially as it relates to agricultural production and energy use. The most critical factors affecting both energy use and agricultural pollution are farming methods. Therefore, a detailed discussion of the important changes in farming methods because of the energy crisis and the possible impact on the environment are presented.

Irrigated vs. Dryland Farming

Reduction in energy supplies as well as high energy prices have an important impact on irrigated farming in the United States. The main reason for a decline in irrigated acres under an energy cirsis is high energy intensity of irrigated crops. One expression of measuring energy intensity is the energy required to produce a given unit of output (Table 6.1). Irrigated crop yields are much higher than dryland crop yields. But, increased energy use for irrigation is more than proportional to the yield increase. Under unrestricted energy supplies (Model A), the amount of energy per unit of output for irrigated crops is about twice as high as for dryland crops. For example, production of a bushel of corn grain requires 16,415 KCAL and 30,832 KCAL for dryland and irrigated corn, respectively. Using 1974 energy prices (.858 cents per 1000 KCAL), that difference is worth about 12 cents per bushel or $12 per acre if corn yield is 100 bushels per acre. Similar differences exist in other crops.

An energy shortage, as simulated here by Model C, leads toward a more efficient utilization of energy both for dryland and irrigated crops. For example, the average energy required to produce a bushel of corn with irrigation declines from 30,832 KCAL under the base run (Model A) to 16,234 KCAL under the 10 percent energy reduction (Model C, Table 6.1). This occurs as some the less energy efficient irrigated acres are removed from production. High energy prices (Model D) result in very minor changes for the per unit output energy requirements both under dryland and irrigated crops. Such small changes can be explained by relatively small changes in reduced tillage acreages, fertilizer application, and relatively small changes in regional production patterns.

The high energy requirements of irrigated crops (Table 6.1) could, however, be improved under alternative water distribution methods. We have not modeled these alternatives because little data are currently available on the relationships between irrigation methods, energy requirements, and crop yields. Some of the results obtained under the energy minimization alternative (Model B), however, indicate that at least some irrigated farming in the West is more energy-efficient than dryland farming. Under the energy minimization alternative (Model B), except for oats, all irrigated crops that come into the solution use less energy (per unit of output) than dryland crops (Table 6.2). This occurs as irrigated farming is limited to those regions where it is as energy efficient as dryland farming.

Reduction of irrigated acres because of an energy crisis can be expected to improve environmental quality. Irrigated crops, in general, are very intensive production processes. Relatively, irrigated crops use more fertilizers and require more pesticides to protect the higher yields. For cotton, however, this might not be so as most of the irrigated cotton is grown in western regions in dry climates. The dry climate reduces the infestation levels and, therefore, allows for reduced pesticide application.

A shift of crop production from irrigated to dryland under an energy shortage might increase soil loss. This is expected as crop production shifts from the arid western regions to the rainfed midwestern and eastern regions where the land is more susceptible to soil erosion. Also, increased land use in the Midwest and the Southeast regions require increased cultivation of fragile land since most of the better land in these regions is already under use. This tendency would be partly offset as more dryland crops are produced on irrigated land.

Reduced Tillage vs. Conventional Tillage

Reduced tillage practices frequently are recommended as a way to reduce soil erosion, increase soil productivity, and reduce production costs. The impact of reduced tillage methods on soil loss was analyzed in previous CARD publications [11, 33].

Reduced tillage practices also are suggested as a way to save and reduced tillage, respectively. The above fuel saving is usually accompanied by higher energy requirements for pesticides.

Energy requirement differences between conventional and reduced tillage methods are the major reason for an increase in the proportion of reduced tillage acreages (Table 6.3) under the energy shortage alternative (Model C). The proportion of reduced tillage increases energy in field operations. For example, the ERS study [16] suggests that "Reduced tillage practices is a major means of achieving these goals (fuel savings)." That study, however, concludes by saying, "From a fossil fuel standpoint, although the direct use of energy is reduced, increased use of pesticides and the energy required to produce reduced-tillage equipment are partly offsetting." Another study [51] says that "Energy inputs for cultural operations in corn and sorghum can be reduced by as much as 83 percent by the use of minimum tillage practices."

In this study, differences in energy requirements between reduced and conventional tillage have been derived from the SCS questionnaire as presented in [32]. For simplicity, it is assumed that differences in energy requirements between conventional and reduced tillage practices are identical to their machinery operating cost differences.[1] Hence, an acre of corn grain in producing area 41 (Iowa) requires 14.6 gallons and 11.6 gallons of diesel fuel when conventional and reduced tillage methods are applied, respectively. In producing area 60 (Missouri) an acre of soybeans requires 15.0 and 11.6 gallons of

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[1]The close relationships between energy needs per acre and machinery operating costs are shown in Table A.1 (Appendix).

Table 6.1. U.S. average fossil fuel (1000 KCAL) required to produce a unit of output by crop for different alternatives in 1985

Crop	Unit	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
				Dryland Crops		
Barley	bu.	13.093	13.005	13.791	13.141	15.574
Corn grain	bu.	16.415	15.536	15.846	16.083	19.203
Corn silage	ton	116.588	106.174	111.034	112.270	127.459
Cotton	bale	1,675.731	1,627.045	1,588.794	1,620.599	1,812.957
Legume hay	ton	346.705	345.480	343.669	346.355	340.331
Nonlegume hay	ton	555.992	545.749	547.774	550.171	616.492
Oats	bu.	11.368	10.251	10.325	10.685	11.995
Sorghum grain	bu.	19.096	16.057	17.529	19.056	24.540
Sorghum silage	ton	109.746	106.649	106.839	107.576	127.739
Soybeans	bu.	17.127	15.775	16.410	17.019	17.361
Sugar beets	ton	87.365	79.747	87.503	85.047	93.253
Wheat	bu.	20.856	19.301	20.227	20.240	25.915
				Irrigated Crops		
Barley	bu.	30.027	10.879	22.356	24.124	25.132
Corn grain	bu.	30.832	13.868	16.234	28.963	26.604
Corn silage	ton	154.162	71.650	131.712	133.861	189.566
Cotton	bale	2,963.243	1,088.160	3,004.383	2,913.593	3,049.113
Legume hay	ton	632.963	181.042	562.969	582.293	608.226
Nonlegume hay	ton	656.716	360.896	444.221	451.954	491.037
Oats	bu.	26.333	13.166	22.678	28.983	30.927
Sorghum grain	bu.	32.182	10.527	31.410	30.587	32.351
Sorghum silage	ton	122.062	56.152	125.884	111.387	131.345
Soybeans	bu.	59.806	10.142	57.958	57.277	70.155
Sugar beets	ton	131.855	68.690	123.346	130.569	133.909
Wheat	bu.	37.435	14.424	30.731	33.786	42.990

Table 6.2. Irrigated crop energy intensities compared with dryland crops under different alternatives in 1985

Crop	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Export (Model E)
			Dryland Crops = 100		
Barley	229.34	83.65	165.11	183.58	161.37
Corn grain	187.83	89.26	102.45	180.08	138.54
Corn silage	132.23	67.48	118.62	119.23	148.73
Cotton	176.83	64.94	184.65	179.78	168.18
Legume hay	182.57	52.40	163.81	168.12	178.72
Nonlegume hay	118.12	66.13	81.10	82.15	79.65
Oats	231.64	128.44	219.64	271.25	257.83
Sorghum grain	168.53	65.56	179.19	160.51	131.83
Sorghum silage	111.22	52.65	117.83	103.54	102.82
Soybeans	349.19	64.29	353.19	336.55	404.10
Sugar beets	150.92	86.13	140.96	153.53	143.60
Wheat	179.49	74.73	151.93	166.93	165.89

diesel fuel under conventional only slightly under high energy prices (Model D) but quite substantially under the 10 percent energy cut (Model C). A wide variation in reduced tillage acreage proportion exists among crops (Table 6.3). No Till Farmer [28] reports the following acreage proportions of reduced tillage in 1975: corn 25 percent, soybeans 19 percent, sorghum grain 20 percent, and small grain 19 percent. Hence, the results of this study pose possibilities of a much larger usage of these methods.

The energy-saving potential of reduced tillage can be judged from crop energy requirements presented in Appendix E. Under energy minimization (Model B), the proportion of reduced tillage acreage increases substantially. For some crops it approaches 100 percent of cropped acres. A comparison between energy requirements under the base run (Model A, Table E.1) and under energy minimization (Model B, Table E.2) should be accomplished with caution. Many variables such as rate of fertilizer application and regional location of production changed between these two models. Therefore, the apparent overall energy savings cannot be attributed alone to reduced tillage practices. Reductions in diesel fuel per acre and increases in energy for pesticides per acre can be attributed, however, to increased reduced tillage acres. For example, a 61 percent increase in corn acreages under reduced tillage practices results in a saving of 1.6 gallon of diesel fuel per acre and an increase of 6,600 KCAL for pesticides per acre. It is hard to judge the overall energy saving potential of reduced tillage from Tables E.1 and E.2. But judging from reduction in

Table 6.3. Percent of reduced tillage acres under different alternatives in 1985

Crop	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
Barley	34.30	71.93	34.36	33.28	28.64
Corn grain	38.35	99.66	67.66	44.18	36.46
Cotton	90.50	92.69	91.72	90.80	87.52
Oats	38.32	87.51	36.73	35.38	51.00
Sorghum grain	5.33	94.92	34.17	7.27	12.75
Soybeans	42.36	97.63	67.43	45.98	52.80
Wheat	22.72	91.32	19.89	21.33	20.39
U.S. average	38.53	87.71	49.24	39.83	42.55

diesel fuel per acre and increased energy for pesticides, the potential is not as large as suggested by Whittmuss [51], and probably does not exceed 20 percent.

Reduced tillage methods are especially important to the North Atlantic, South Atlantic, and South Central regions (Table 6.4). In those regions, reduced tillage is likely to have a real energy saving potential as reduced tillage practices have much more energy saving potential for row crops than for small grain crops.

The energy saving potential of reduced tillage practices are dependent both on the location of the crop and the type of crop grown. The most intensive row crops--corn, sorghum, and soybeans--can reduce energy use significantly as reduced tillage is applied. But again, some of the energy saving under reduced tillage is offset as more herbicides must be used. Farmers who move toward reduced tillage not only have to acquire a new skill but must invest in reduced tillage equipment. Improving farming skills and the different equipment required for a successful reduced tillage system, slow the adoption considerably.

Nitrogen Fertilizer Application

Intensive agricultural production is typically characterized by a high rate of fertilizer application, especially inorganic nitrogen fertilizers. At the present time, there is no agreement between researchers on the exact nature of the relationship between nitrogen application and nitrate concentration in water supplies. Some researchers

Table 6.4. Percent of reduced tillage acres under different alternatives by regions in 1985

Major Zone	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
North Atlantic	76.47	85.91	87.87	82.97	74.96
South Atlantic	70.44	97.98	88.03	73.80	86.04
North Central	28.15	91.36	43.12	29.20	30.08
South Central	47.80	89.04	61.38	51.12	55.22
Great Plains	30.24	73.48	31.62	30.71	31.07
Northwest	32.84	77.28	22.89	23.00	25.85
Southwest	22.41	23.33	30.24	23.28	27.43
United States	38.54	87.71	49.24	39.83	42.55
			Changes from Model A		
North Atlantic	100.00	111.88	114.54	108.61	98.49
South Atlantic	100.00	141.02	124.96	104.75	130.67
North Central	100.00	330.88	155.30	103.49	111.49
South Central	100.00	196.08	130.66	107.25	134.61
Great Plains	100.00	249.27	107.65	104.68	108.37
Northwest	100.00	289.31	78.59	78.47	102.15
Southwest	100.00	123.20	141.96	102.97	152.51
United States	100.00	228.80	130.22	104.32	119.24

advocate that reducing per acre application of nitrogen would have a significant impact on nitrate concentration. On the other hand, some argue that to reduce nitrate concentration in water we must reduce the total amount of nitrogen fertilizers used yearly in the United States [43].

Concern has focused particularly on the buildup of nitrate because of its possible role in the disease known as "blue baby". Recently the Environmental Protection Agency (EPA) has called for a setting of maximum nitrate concentration standards in most of the nation's water systems. The state of Illinois was especially active in conducting hearings on nitrate pollution and considering regulations to reduce nitrogen fertilizer applications. Most researchers would agree that reduced nitrate concentration in the nation's water systems would be possible if farmers apply less nitrogen fertilizer per acre.

Results presented previously indicate that total nitrogen use would change very little even under an energy crisis. Most of the changes in overall nitrogen use under an energy crisis result in a reduced use of inorganic nitrogen and greater use of manure and legume crops.

Aside from the high export alternative, per acre nitrogen use generally decreases (Table 6.5) in comparison with the base solution (Model A). Thus an energy crisis, causing rationing or high prices for energy, could be beneficial to the environment.

In short, an energy shortage and high energy prices might achieve some of the environmental standards long sought. Of course, high exports

Table 6.5. U.S. average nitrogen fertilizer application under different alternatives in 1985

Crop	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			Pounds of Nitrogen per Acre		
Barley	44.9	40.5	45.7	45.7	54.1
Corn grain	89.8	82.2	84.4	85.0	133.0
Corn silage	85.8	68.9	76.5	77.7	111.7
Cotton	95.9	71.6	85.3	87.7	107.5
Nonlegume hay	49.9	46.0	48.1	48.6	67.6
Oats	48.2	38.7	39.1	52.3	58.1
Sorghum grain	52.1	45.2	46.6	50.6	94.6
Sorghum silage	44.7	48.4	50.0	52.5	62.2
Sugar beets	88.6	82.9	91.3	87.3	103.9
Wheat	34.9	34.1	32.5	33.3	56.1
U.S. average	40.2	36.6	37.8	38.4	58.1
			Changes from Model A		
Barley	100.00	90.20	101.78	101.78	120.49
Corn grain	100.00	91.54	93.97	94.65	148.11
Corn silage	100.00	80.30	89.16	90.56	130.19
Cotton	100.00	74.66	88.95	91.45	112.10
Nonlegume hay	100.00	92.18	96.39	97.39	135.47
Oats	100.00	80.29	81.12	108.51	120.54
Sorghum grain	100.00	86.76	89.44	97.12	181.57
Sorghum silage	100.00	108.28	111.86	117.45	139.15
Sugar beets	100.00	93.57	103.05	98.53	117.27
Wheat	100.00	97.71	93.12	95.42	160.75
U.S. average	100.00	91.05	94.03	95.52	144.53

increase both total nitrogen use and the application rate. But as long as exports are not increased substantially, an energy crisis could lead to an improved water quality.

Pesticide Application

In contrast with the reduction of nitrogen fertilizer application, pesticide (herbicides and insecticides) use increases under an energy crisis. This observation can be made from the amount of energy (10^{12} KCAL) used for pesticides under different alternatives (Table 6.6). The sharpest increase in pesticide use (28 percent) takes place under the energy minimization (Model B). This is because of a large increase in the proportion of reduced tillage under this alternative (Table 6.3). Hence, some of the energy saved by increased use of reduced tillage would be offset by increased application of pesticides. Conflict between energy saving and improved environmental quality thus exists.

If we ignore the energy minimization alternative (Model B) as politically infeasible, we observe that other alternatives have only a small impact on pesticide use. Under the 10 percent energy reduction (Model C), energy use for pesticides increases by only 7 percent. High energy prices (Model D) have a negligible impact on total pesticide use. Surprisingly, high exports (Model E) increase pesticide use by less than 7 percent. The adverse environmental impact of increased pesticide use under an energy shortage, high energy prices, and even high exports do not seem to be serious. Whether increased environment damage because of a larger application of pesticides is worth the

Table 6.6. Energy use for pesticides under different alternatives in 1985 [a]

Crop	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			10^{12} KCAL		
Barley	.2702	.3300	.2482	.2262	.2755
Corn grain	1.6195	2.1072	1.8232	1.6782	1.8716
Corn silage	.0618	.0700	.0617	.0626	.0459
Cotton	2.3751	2.4110	2.4406	2.4708	2.2969
Legume hay	.0858	.0902	.0900	.0879	.1151
Nonlegume hay	.0167	.0168	.0160	.0166	.0165
Oats	.2116	.4743	.2247	.2162	.2596
Sorghum grain	.3088	.5817	.4029	.3216	.3752
Sorghum silage	.0935	.0978	.0993	.0962	.0471
Soybeans	1.6821	2.0719	1.8444	1.7120	1.7365
Sugar beets	.1091	.0932	.1068	.1031	.1115
Wheat	.5401	1.0610	.5377	.5260	.7225
Total	7.3740	9.4052	7.8957	7.5176	7.8741
			Changes from Model A		
Barley	100.00	122.13	91.86	83.72	101.96
Corn grain	100.00	130.11	112.58	103.62	115.57
Corn silage	100.00	113.27	99.84	101.29	74.27
Cotton	100.00	101.51	102.76	104.03	96.71
Legume hay	100.00	105.13	104.89	102.45	134.15
Nonlegume hay	100.00	100.60	95.81	99.40	98.80
Oats	100.00	224.15	106.19	102.17	122.68
Sorghum grain	100.00	188.37	130.47	104.14	121.50
Sorghum silage	100.00	104.60	106.20	102.89	50.37
Soybeans	100.00	123.17	109.65	101.78	103.23
Sugar beets	100.00	85.43	97.89	94.50	102.20
Wheat	100.00	196.44	99.55	97.39	133.77
Total	100.00	127.54	107.07	101.95	106.78

[a]Total might not add up due to rounding.

energy saving is a matter which cannot be handled adequately by this study.

Summary and Implications

Energy use and environmental quality in agriculture are closely related via farming methods. The most important impact of an energy crisis on farming methods is a substantial drop in irrigated acres. This is because irrigated crops require a lot more energy per unit of output than dryland crops. Energy use per unit of output varies substantially, not only between dryland and irrigated crops but also among dryland crops themselves. An energy shortage, as well as high energy prices, would result in a more energy-efficient production pattern. In general, the increased yield because of irrigation does not compensate for increased energy use by irrigated crops. Some irrigated farming is, however, more energy efficient than dryland farming. However, their acreages are relatively small compared with other less energy efficient irrigated farming. Reduced irrigation would, in general, mean improved environmental quality because irrigated crops use relatively more fertilizer and pesticides than dryland crops in the same regions. Also the water applied tends to wash these elements into the nation's water systems.

Reduced tillage methods are very important for reducing soil loss and preserving soil productivity. Reduced tillage practices can also save energy. However, that energy saving is not as large as claimed by another study [51]. In addition, increased energy for pesticides and reduced tillage equipment tends to offset some of the energy savings. Despite the energy saving potential and reducing soil loss, reduced tillage methods are adopted slowly because they require better farming skill and different equipment. Agricultural policy encouraging reduced tillage methods would improve water quality and would also save some energy.

Concern for nitrogen use in agriculture arises because it is related to the disease known as "blue baby." Reduction in total nitrogen use as well as a reduction in per acre application has the potential of reducing nitrate concentration in water supplies. Under an energy shortage or high energy prices nitrogen application per acre is reduced. But high exports require a substantial increase in nitrogen application.

The net environmental impacts of the energy crisis in agriculture are somewhat ambiguous. Three pollutants are considered in this study. These are sediment, nitrate, and pesticides. As pointed out above, an energy crisis could be beneficial to the environment as far as nitrate pollution is concerned. Pesticide use increases slightly under an energy shortage and high energy prices. But unless there is a major shift toward reduced tillage methods, the increased use of pesticides is not deemed to be serious.

Finally, we must ask what would happen to soil erosion under an energy crisis? Unfortunately, this model is unable to compute total soil erosion. Two factors influence soil erosion. The first factor is the substitution of land for energy which takes place under both reduced energy and high energy situations. This substitution can be expected to increase soil loss because additional land brought into production is not only of low yields, but also is characterized by high susceptibility to soil erosion. On the other hand, increased utilization of reduced tillage which also takes place under reduced energy and high energy prices would, in the long-run, reduce soil erosion. Hence, the net national change in soil erosion is unclear. Our experience with previous soil loss models [11, 33], seems, however, to indicate that the reduction of soil erosion because of increased utilization of reduced tillage methods would probably be more than enough to offset the increased soil erosion occurring because of additional cropland brought into production. Whether or not that is the case would be examined by other studies. These studies would be able to not only quantify energy use in agriculture under different energy situations but would also be able to quantify the environmental consequences in terms of nitrate and pesticide pollution and soil erosion.

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APPENDIX A: DERIVATION OF ENERGY USE FOR CROP PRODUCTION

Described here are the derivation of energy use coefficients for the endogenous crops. Included in this appendix are derivation of energy use for field operations and energy use for crop crying. (The derivation of energy use for irrigation, pesticides, and fertilizers is described in the following appendices.)

Energy Use for Field Operations

Two basic pieces of information are used in estimating energy requirements for field operations by producing areas and tillage practices. The first consists of machinery costs defined in the study for each of the endogenous crops by producing areas and for each of the tillage practices employed. The second is weighted least squares (WLS) estimates of energy needs (1000 KCAL) as a function of machinery costs. Machinery costs, as well as other production costs, have been developed and maintained at the Center for Agricultural and Rural Development (CARD). The development of crop costs is presented in "A Model of Regional Agricultural Analysis" [32].

For each endogenous crop, a weighted least squares (WLS) regression model has been fitted (Table A.1). Such a model has the form:

$$Y' = Y * \sqrt{A} \tag{A.1}$$

$$X' = X * \sqrt{A} \tag{A.2}$$

$$Y' = a + bX' \tag{A.3}$$

where:

Y is the energy requirements per acre in 1000 KCAL for field operations,

Table A.1. Weighted least squares estimates of energy needs (1,000 KCAL) by crops as a function of machinery costs in dollars[a]

Crop	No. of Observations	Regression Coefficients Intercept	Slope	F Value	R^2 Value	Comments
Barley	62	230.6160	2.3057	891.85	.97	
		(12.45)	(2.88)			
Corn grain	75	409.2747	2.5453	6,015.54	.99	
		(24.82)	(5.18)			
Corn silage	51	311.8201	8.5775	1,901.36	.99	
		(9.19)	(11.95)			
Cotton	28	640.1965	3.4886	1,265.55	.99	Eastern Producing Regions
		(11.17)	(4.99)			(PA 1 to 47)
Cotton	16	216.2711	9.3420	192.34	.97	Western Producing Regions
		(3.87)	(6.40)			(PA 48 to 105)
Hay	56	104.7871	18.7553	578.30	.96	All Hay Crops
		(1.86)	(11.28)			
Oats	70	152.0083	4.7807	1,780.58	.97	
		(6.52)	(2.96)			
Sorghum grain	72	264.9331	5.9048	720.40	.95	
		(9.51)	(6.59)			
Sorghum silage	6	121.2734	11.9686	82.10	.98	
		(1.67)	(6.00)			
Soybeans	25	250.7852	10.2517	726.05	.98	South Eastern Producing
		(4.94)	(5.14)			Regions
Soybeans	46	249.7712	6.4342	7,042.25	.99	All Other Producing Regions
		(9.72)	(5.91)			
Sugar beets	13	0.0000	14.0472	246.25	.95	Intercept is not significant
		(0.00)	(15.69)			at .05 level
Wheat	120	182.4499	6.3921	1,974.38	.97	
		(11.44)	(7.53)			

[a]Numbers in parentheses are "t test" values.

Source: Economic Research Service [15].

Y' is the transformed value of Y,

A is the number of the crop acres in the region,

X is the machinery costs per acre in dollars,

X' is the transformed value of X,

a is the estimated value of the intercept, and

b is the estimated value of the slope or the regression coefficient.

Data for the above regression models have been derived from the "Firm Enterprise Data System" (FEDS) developed by the Economic Research Service, U.S. Department of Agriculture [15]. The per acre KCAL energy requirement has been derived by converting diesel fuel and gasoline into 1000 KCAL of energy (see Appendix F for conversion rates).

The use of weighted least squares (WLS) regression rather than an ordinary least squares regression (OLS) is required because the observations in the regression model represent regions with varying number of acres. Hence, it is desirable to give more weight to regions with greater crop acreages. The weights used for each crop consist of square root of the number of acres represented by each observation. The weighted regression method also corrects for heteroskedasticity which usually occur when using aggregated cross section data. Some discussion of weighted least squares regression methods appears in almost all basic econometric textbooks. But, an excellent discussion of the method appears in Kmenta [26].

The relationships between energy use under reduced and conventional tillage is assumed to be identical to the relationships between machinery costs under reduced and conventional tillage. Therefore, the percentage reduction in energy use, for each crop in each region because of reduced tillage, is equal to the percentage reduction in machinery costs as defined in the Soil Conservation Service's questionnaires [33].

Energy Use for Crop Drying

The estimation of energy requirements for crop drying is an extremely difficult task. Crop drying energy needs are a function of crop yields, crop acreages, fuel and crop prices, and , most important, weather conditions. Adverse weather conditions can effect both the length of the growing season and the moisture content of the grain during harvesting. The length of the growing season, is an important factor determining the proportion of the yield that must be artifically dried.

To simplify the estimation of crop drying, a normal or average weather situation is assumed. Among all the endogenous crops in the study, corn and sorghum grain require a considerable amount of drying [7]. The proportions of crop yields artifically dried in an average weather year for corn and sorghum grain are derived from the FEDS [15]. For simplification, only liquid petroleum gas (LPG) is assumed to be used for drying.

Corn drying assumes to require one gallon of LPG for every 6.5 bushels of corn grain dried; and it reduces the moisture content by 10 percent age points. Sorghum drying assumes to require one gallon of LPG for every 12 bushels of sorghum grain dried [7]. Therefore, for a given region, the LPG per acre required for drying can be written as:

$$LPG = (Y*PD)/DC \qquad (A.4)$$

where:

LPG is the amount of LPG in gallon per acre required for drying,

Y is the crop yield in bushels per acre,

PD is the average proportion of the yield dried yearly, and

DC is the number of bushels which can be dried with one gallon of LPG (6.5 for corn and 12 for sorghum)

APPENDIX B: ENERGY USE FOR IRRIGATION[1]

Irrigation is one of the major users of energy in agricultural production. Energy required for irrigation varies widely across the nation as a function of the water source and the irrigation methods. Two primary sources of water are used for irrigation, surface water (streams and lakes) and ground water as obtained from wells. The importance of irrigation to crop production varies substantially from area to area. Examination of state data suggests that it is practically impossible for some states to produce crops without irrigation while others require little or no irrigation for crop production. In general, irrigation is very important in the 17 Western states [46].

Energy and Irrigation Relationships

The basic relationship used in this study assumes that energy requirements for irrigation in each of the irrigated regions can be expressed by the following function:

$$IE_i = f(PD_i, PE, ME_j, SH_i, RL_i, WP_{ij}, WS_i, IB_i, GW_i) \qquad \text{(B.1)}$$

i = 48,..., 105 for the 58 regions defined in the 17 Western states.

j = 1,..., 5 for the five major types of power units; electric, gasoline, diesel, LPG, and natural gas;

IE_i is the energy required to obtain and apply one acre-foot of water in the ith region,

---

[1]A more detailed explanation that includes some of the data, is available in Dvoskin, Heady, and Nicol [12].

PD_i is the average pumping depth of ground water in the ith region,

PE is the average efficiency of water pumps in the 17 Western states,

ME_j is the efficiency of the jth power unit in converting fuel energy to mechanical energy,

SH_i is the weighted average head required for sprinkler irrigation in the ith region including friction losses,

WP_{ij} is the proportion of the total energy used for irrigation in the ith region by the jth power unit,

WS_i is the proportion of the irrigated acres having the water applied by sprinkler in the ith region,

IB_i is the energy required to supply one acre-foot of water from surface sources in the ith region, and

GW_i is the proportion of water used for irrigation obtained from ground water in the ith region.

Many variables such as rate of pumping, size of power units, variations in pumping depth between seasons, etc., are omitted from equation B.1. However, with the current data complete accounting for all such factors, while important, cannot be done successfully. The following sections detail the derivation, assumptions, constant parameters, sources, and use of the data required to quantify equation B.1.

Pumping Depth

For the purpose of this study, pumping depth is defined as the yearly average depth (in feet) relative to the ground surface, from which water is pumped for irrigation. Pumping depths, by state, have been estimated by irrigation experts. The regional variations in pumping depths within the 17 Western states were obtained by collecting water level and well depth information on more than 10,000 wells. For the 17 Western states, the average pumping depth is 196 feet. The deepest pumping depth is in producing area 78 (New Mexico and Northwest Texas) where water for irrigation is pumped from 357 feet.

<u>Water pumping efficiency</u> Pump efficiencies vary greatly as a function of the pump type, rate of pumping, and the pump age. Although a good pump can have efficiency as high as 75 percent, most pumps can be expected to have a much lower efficiency rate than that. Pump efficiency is assumed to be a constant equal to 60 percent and applied uniformly across the 17 Western states [25].

<u>Type of power units and their energy efficiency</u> Major losses of energy normally occur in the conversion of fuel energy to mechanical energy such as powering engines and turning generators for electricity production. In the case of electricity, losses occur both in the conversion of fossil fuel to electricity and electricity to mechanical energy. It is estimated [10] that in 1975, 10,560 BTU of fossil fuel energy was required to produce 1 KWH of electricity for final consumption, equivalent to 3,409.52 BTU. This gives an output-input ratio for energy conversion in the electricity industry in 1975 of 32.287 percent which implies that about two-thirds of the energy consumed by the electric industry is lost in conversion of fossil fuel to electricity.

No specific data are available on regional differences in power unit efficiencies. Therefore, it assumes that the following efficiency rates (Table B.1), apply uniformly to all power units in the 17 Western states.

Table B.1. Power unit energy efficiencies for common motor use in water pumping[a]

Power Unit	Percent Efficient
Diesel engine	26.8
Gasoline engine	23.2
Natural gas engine	19.5
LPG engine	24.0
Electrical motors	28.4[b]

[a]Source: Pair [34].

[b]Equal to 88 percent motor efficiency [34] times 32.287 percent conversion efficiency [10].

The proportion of the power units employed in each region is derived by weighting the state proportion of power units [24]. Only five types of power units are dealt with: gasoline, natural gas, liquid petroleum gas (LPG), diesel and electric. Assuming no substantial differences in power unit sizes, operation hours and overall efficiency, the proportion of the total energy used in irrigation by each of the power units for a given region is approximately equal to the power unit's relative proportion in the total number of power units used for irrigation in the region.

$$RE_i = \sum_{j=1}^{5} WP_{ij} ME_j \qquad (B.2)$$

$i = 48, \ldots, 105$ for the 58 regions defined in the 17 Western states;

$j = 1, \ldots, 5$ for the five types of power units.

where: RE_i is the weighted efficiency in converting fuel energy to work use in pumping water in the ith region,

WP_{ij} is the proportion of the jth power unit employed in water pumping in the ith region,

ME_j is the efficiency of the jth power unit (Table B.1).

For the 17 Western states, the average energy efficiency is 26.5 percent,and it varies from as low as 22.9 percent to 28.4 percent in regions where all the irrigation power units are electric.

<u>Energy for water pumping</u> The energy required to pump one acre-foot of water from ground sources to the surface level is calculated by the following equation:

$$ER_i = (PD_i * .880945)/(RE_i * .60) \qquad (B.3)$$

$i = 48, \ldots, 105$ for the 58 regions defined in the 17 Western states.

ER_i is the energy in 1000 KCAL required to pump one acre-foot of water from the underground source to the surface level in the ith region,

PD_i is the pumping depth in feet in the ith region,

RE_i is the regional weighted energy efficiency from equation (B.2),

.880945 is the amount of energy in 1000 KCAL required to lift one acre-foot of water one foot, and

.60 is the pumping efficiency.

On the average, it takes 1,134,660 KCAL (equivalent to 36.3 gallons of gasoline) to pump one acre-foot of water from the average depth of 196 feet to ground level.

Energy required for surface water   The majority of surface-water-supply projects do not require any energy because the water moves by gravity from reservoirs to fields. Some of the Bureau of Reclamation's projects, however, consume large amounts of electricity when providing water for irrigation. The yearly average KWH consumption of the Bureau's projects, obtained from unpublished Bureau of Reclamation data, is adjusted for nonagricultural uses. For some regions, the energy required to supply one acre-foot of water from surface sources can be substantial. For example, in 1973 the Salt River irrigation project (Central Arizona) consumed 648.6 million KWH and supplied 641,975 acre-feet of water for irrigation, for an average of 1010 KWH (868,046 KCAL) per acre-foot of water supplied for irrigation.

Energy required for sprinkler irrigation   Sprinkler irrigation is a very energy-intensive operation. This is mainly because of the high pressure required to rotate the system and to distribute the water equally across the field. The head (pressure) required is mainly a function of the sprinkler system employed. For each region the proportion of the six major sprinkler irrigation methods used in the United States is determined from [24]. The head required for each of these methods (Table B.2) includes friction losses and is applied uniformly across the 17 Western states.

Table B.2. Head required and friction losses in sprinkler irrigation methods[a]

Sprinkler Method	Head (feet)
Tow line/side roll	175
Center pivot	196
Hand rove	173
Solid set	175
Gun	312
Drip	115

[a]Source: Batty et al. [2].

Energy for supplying water to the field The weighted average energy requirement to obtain one acre-foot of water at the head of the field (prior to application) is based on weighting ground and surface water by their 1975 proportions obtained from an unpublished paper by the Economic Research Service, U.S. Department of Agriculture.

Energy Requirement for Irrigation

The overall energy requirements to obtain and apply one acre-foot of water in each region (Table B.3) is determined by adding the energy for sprinkler irrigation (weighted by the proportion of sprinkler irrigation acreages) to the energy required to supply water to the field.

On the average, it takes 836,430 KCAL (3,319,170 BTU) to obtain and apply one acre-foot of water in the 17 Western states. Using the 1974 proportion distribution of power units [24], the average energy requirement is equivalent to the sum of .3 gallons of gasoline, 776.6 cubic feet of natural gas, 2.1 gallons of LPG, 1.0 gallons of diesel, and 202.5 KWH of electricity.

The distribution of the energy requirement coefficients across the 17 Western states (Table B.3) presents a close relationship between pumping depth, ground water proportion and the energy requirements. The deep ground water in Nebraska, Kansas, Oklahoma, Texas, New Mexico, Arizona, and Southern California is in sharp contrast to the shallow ground water and much larger proportion of surface water in Colorado, Wyoming, Montana, Utah, and Nevada.

Table B.3. Energy requirement coefficients and fuel needs to obtain and apply one acre-foot of water in the 17 Western states

Producing Area	Total Energy 1000 KCAL	1000 BTU	Fuel Needs Gasoline Gallon	Nat. Gas[a]	LPG Gallon	Diesel Gallon	Elect. KWH
48	152.81	606.38	1.5	16.9	0.1	0.6	28.9
49	163.45	648.62	1.4	16.7	0.1	0.6	33.3
50	148.12	587.77	1.4	16.5	0.1	0.6	27.8
51	139.78	554.68	0.5	14.7	0.1	0.4	39.1
52	657.29	2,608.29	1.7	47.2	4.4	4.0	129.7
53	813.72	3,229.03	1.4	179.7	8.2	6.6	109.4
54	236.65	939.10	0.1	58.3	1.1	0.6	63.4
55	552.98	2,194.35	0.2	308.2	5.3	5.0	60.3
56	520.94	2,067.22	0.2	290.5	5.0	4.7	56.8
57	633.93	2,515.59	3.8	193.7	4.3	5.8	58.8
58	852.74	3,383.88	0.5	961.4	7.3	3.8	101.5
59	1,197.93	4,753.67	0.4	700.0	11.6	10.7	129.1
60	366.57	1,454.65	2.3	187.2	5.1	1.6	24.3
61	557.87	2,213.77	4.5	77.4	9.1	2.0	41.9
62	182.77	725.28	0.2	47.6	1.1	0.3	48.1
63	1,456.53	5,779.89	1.0	3,469.0	13.2	2.9	67.7
64	360.58	1,430.87	2.2	219.6	5.0	1.1	27.7
65	2,239.95	8,888.70	1.5	4,463.9	10.7	3.2	243.9
66	1,117.56	4,434.76	1.2	2,022.3	6.7	2.2	114.1
67	1,679.02	6,662.79	0.5	3,744.9	4.9	1.4	189.3
68	1,144.46	4,541.49	1.0	2,174.8	6.1	2.0	119.5
69	631.00	2,503.98	0.4	889.0	6.8	2.1	58.2
70	291.66	1,157.37	0.1	647.5	0.9	0.3	31.8
71	510.10	2,024.20	0.2	1,137.7	1.5	0.4	57.5
72	1,666.29	6,612.25	0.7	3,577.1	5.8	1.7	187.9
73	716.99	2,845.21	0.2	1,599.2	2.1	0.6	80.8
74	1,130.28	4,485.25	0.5	2,412.6	4.1	1.2	127.4
75	720.60	2,859.50	0.2	1,607.2	2.1	0.6	81.2
76	1,205.87	4,785.20	0.4	2,689.6	3.5	1.0	135.9
77	251.93	999.72	0.2	65.6	1.5	0.4	66.3
78	568.96	2,257.79	0.7	835.0	4.6	1.3	64.1
79	1,414.36	5,612.53	0.5	3,154.6	4.2	1.2	159.4
80	1,465.48	5,815.39	2.3	1,634.3	15.4	4.2	165.2
81	289.23	1,147.74	0.1	645.1	0.9	0.2	32.6
82	99.21	393.69	0.1	14.3	0.1	0.3	29.7
83	165.71	657.60	0.2	42.6	1.0	0.3	43.8
84	180.19	715.02	0.2	54.8	0.9	0.4	45.6
85	434.16	1,722.86	0.1	343.3	0.6	0.2	120.2
86	845.28	3,354.28	0.0	179.1	0.0	0.1	296.9
87	2,152.42	8,541.36	0.1	1,323.8	0.5	0.1	667.4

[a]Natural gas in cubic feet.

Table B.3 (continued)

Producing Area	Total Energy 1000 KCAL	1000 BTU	Fuel Needs Gasoline Gallon	Nat. Gas[a]	LPG Gallon	Diesel Gallon	Elect. KWH
88	199.66	792.29	0.4	14.8	0.1	0.7	59.4
89	366.94	1,456.10	0.8	27.3	0.2	1.6	103.4
90	138.88	551.11	0.0	0.0	0.1	0.8	40.7
91	37.90	150.39	0.0	0.0	0.0	0.2	11.1
92	189.07	750.30	1.6	19.7	0.1	0.7	38.8
93	1,317.02	5,226.25	0.0	0.0	0.0	0.0	494.9
94	533.11	2,115.50	0.2	29.1	0.2	0.1	191.5
95	940.78	3,733.26	0.3	40.6	0.2	0.2	341.2
96	473.42	1,878.65	0.0	0.0	0.0	0.0	177.9
97	670.45	2,660.50	0.0	0.0	0.0	0.0	251.9
98	392.32	1,556.84	0.0	0.0	0.0	0.0	147.4
99	325.23	1,290.58	0.0	10.8	0.0	0.0	121.1
100	496.45	1,970.02	0.0	24.5	0.0	0.0	184.1
101	823.45	3,267.66	0.0	46.9	0.0	0.0	304.7
102	511.05	2,027.99	0.0	38.0	0.0	0.0	188.2
103	787.12	3,123.49	0.0	58.5	0.0	0.0	289.9
104	398.86	1,582.79	0.0	29.7	0.0	0.0	146.9
105	892.38	3,541.18	0.0	66.3	0.0	0.0	328.6
Average	836.43	3,319.17	0.3	776.6	2.1	1.0	202.5

APPENDIX C: ENERGY FOR FERTILIZERS AND PESTICIDES

Fertilizers, and more specifically nitrogen fertilizers, are one of the largest energy consumers in agriculture. Two pieces of information are used in estimating energy requirements for a pound of fertilizer nutrient. The first are estimates of energy requirements to produce one ton of fertilizer obtained from [50]. The second are the quantities of different fertilizers consumed in the United States in 1974 by type of fertilizer [21]. These quantities are used to convert the energy requirements for different fertilizers into common units of nutrients, N, P, and K (Table C.1).

Table C.1. Energy requirements for production of one pound of fertilizer nutrient N, P, and K

Fertilizer Nutrient	Natural gas Cubic-feet	Electricity KWH	KCAL[a]
N	30.6743	.119974	8,573.7193
P	1.0300	.060000	436.7475
K	1.2750	.087700	576.3680

[a]The KCAL figures are the summation of the natural gas and electricity converted to KCAL units.

Energy consumed by crop production as pesticides is assumed to be directly related to the quantities of pesticides applied to the crops. The cost per acre of pesticides (insecticides and herbicides) by crops and producing areas are derived from the 1971 pesticide use survey [14]. The cost per acre of pesticides when multiplied by the proportion of acres treated is assumed to represent the cost of pesticides under conventional tillage. For reduced tillage, it is assumed that costs of herbicide treatments for a crop grown under reduced tillage are the same as those of the other treated acres in the region.

In a few cases where most of the crop acreage is treated and, therefore, no difference in herbicide use occurred, it is assumed that reduced tillage requires 25 percent more herbicide than conventional tillage. Silage and hay crops are not defined with reduced tillage. Therefore, energy needs for pesticides by these crops do not change between conventional and reduced tillage.

For the purpose of converting pesticide costs to energy, prices per pound of pesticides for each of the endogenous crops have been obtained from the Economic Research Service [15]. It is then assumed that the manufacture of one pound of pesticide required, on the average, 33,000 KCAL.[1] Thus, energy use (KCAL) for pesticides is equal to pesticide costs divided by pesticide prices and multiplied by 33,000 KCAL.

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[1] Pimentel, David, Cornell University, personal communication, July 1975.

APPENDIX D. ENERGY PRICES, 1972 AND 1974 BY MARKET REGION.

Market Region	Diesel[a] $/Gallon 1972	Diesel[a] $/Gallon 1974	LPG[a] $/Gallon 1972	LPG[a] $/Gallon 1974	Electricity[a] $/KWH 1972	Electricity[a] $/KWH 1974	Natural Gas[b] $/1000 Feet ^{3} 1972	Natural Gas[b] $/1000 Feet ^{3} 1974
1	.1982	.3799	.2173	.4195	.0253	.0320	1.1542	1.5358
2	.1993	.3795	.1909	.3759	.0235	.0290	.8197	1.0007
3	.1930	.3864	.1665	.3240	.0213	.0283	.6870	.8502
4	.1985	.4011	.1879	.3245	.0212	.0283	.6051	.8058
5	.2054	.3769	.1954	.3407	.0205	.0298	.4932	.6330
6	.2107	.3545	.1917	.3483	.0212	.0283	.4650	.6271
7	.1997	.3779	.1707	.3216	.0232	.0289	.6483	.8403
8	.1841	.3746	.1735	.3040	.0235	.0292	.6190	.8416
9	.1880	.3761	.1766	.3164	.0220	.0277	.5543	.6910
10	.1740	.3446	.1643	.3234	.0228	.0290	.4063	.5402
11	.1847	.3587	.1666	.3199	.0215	.0304	.3310	.5107
12	.1860	.3507	.1694	.3121	.0235	.0292	.6005	.7453
13	.1958	.3647	.1594	.3043	.0238	.0289	.5701	.7335
14	.1762	.3571	.1604	.3020	.0251	.0278	.4957	.6137
15	.1841	.3520	.1511	.2958	.0249	.0280	.4940	.6338
16	.1805	.3617	.1646	.2910	.0231	.0249	.4120	.5269
17	.1677	.3491	.1340	.2783	.0253	.0275	.3987	.5320
18	.1609	.3419	.1245	.2761	.0251	.0271	.3116	.4699
19	.1582	.3241	.1338	.2881	.0249	.0269	.2776	.5637
20	.1580	.3220	.1320	.2850	.0249	.0269	.2702	.5940
21	.1703	.3516	.1409	.2846	.0213	.0230	.3222	.4597
22	.1590	.3263	.1316	.2836	.0244	.0264	.2805	.5714
24	.1640	.3387	.1326	.2790	.0223	.0240	.3127	.5151
25	.1767	.3712	.1526	.2918	.0205	.0220	.3162	.4668
26	.1810	.3561	.1580	.2983	.0205	.0220	.4466	.5685
27	.2130	.3685	.1928	.3185	.0187	.0233	.4612	.6303
28	.2130	.3670	.1950	.3200	.0186	.0234	.4577	.6262
U.S.	.1890	.3580	.1560	.3020	.0223	.0266	.4616	.6621.

[a]Source: Statistical Reporting Service [39, 40, 41].

[b]Source: American Gas Association [1].

APPENDIX E. DRYLAND AND IRRIGATED CROP ENERGY BUDGETS FOR DIFFERENT ALTERNATIVES.

Table E.1. U.S. average per acre energy use coefficients by crops under the base run (Model A) in 1985

Crop	Mach. Diesel (gal.)	Pest. KCAL (1000)	Fertilizer Elect. (KWH)	Fertilizer Nat. gas (1000 ft)	Crop Drying LPG (gal.)	Irrigation Diesel (gal.)	Irrigation Nat. gas (1000 ft)	Irrigation LPG (gal.)	Irrigation Elect. (KWH)	Total KCAL[a] (1000)
					Dryland crops					
Barley	7.7	11.6	7.0	1.4						681.104
Corn grain	13.6	24.6	14.5	2.8	8.5					1,502.648
Corn silage	23.3	16.2	15.0	2.7						1,606.587
Cotton	19.2	306.5	14.6	3.0						1,826.547
Legume hay	25.9	1.6	5.7	0.1						970.773
Nonlegume hay	20.9	0.7	9.2	1.6						1,187.992
Oats	7.6	13.7	7.4	1.5						706.097
Sorghum grain	12.5	15.1	7.0	1.6	0.5					921.562
Sorghum silage	16.0	13.5	6.0	1.4						965.768
Soybeans	12.9	21.7	5.2	0.2						542.576
Sugar beets	12.1	71.8	18.5	2.8						1,312.215
Wheat	9.0	9.7	5.2	1.1						635.260
					Irrigated Crops					
Barley	11.4	28.1	6.0	1.4		1.4	1.1	2.9	360.3	2,184.781
Corn grain	13.4	57.2	12.2	2.8	10.0	4.0	3.3	11.5	230.2	3,454.747
Corn silage	16.9	35.2	11.0	2.6		1.8	1.9	4.0	268.9	2,770.295
Cotton	23.4	89.2	13.2	3.0		1.8	2.7	4.3	654.7	4,385.599
Legume hay	20.2	4.6	6.3	0.2		2.2	0.8	3.1	748.8	3,152.156
Nonlegume hay	13.3	0.2	6.8	1.5		2.2	0.0	0.2	222.5	1,589.252
Oats	15.3	24.0	6.0	1.5			0.0		407.9	2,069.748
Sorghum grain	15.3	18.1	7.3	1.6	0.6	2.2	2.9	6.7	315.9	2,895.708
Sorghum silage	17.3	15.0	5.8	1.4		7.7	0.6	8.2	191.8	2,158.059
Soybeans	13.6	6.6	1.6	0.1		5.1	3.3	8.2	206.2	2,338.425
Sugar beets	20.5	52.7	12.0	2.7		2.5	0.9	3.9	345.4	2,890.265
Wheat	11.9	14.2	4.5	1.1		1.9	1.5	4.7	275.2	2,045.955

[a]Total KCAL may not add up due to rounding errors. See Appendix F for conversion factors.

Table E.2. U.S. average per acre energy use coefficients by crops under energy minimization (Model B) in 1985

Crop	Mach. Diesel (gal.)	Pest. KCAL (1000)	Fertilizer Elect. (KWH)	Fertilizer Nat. gas (1000 ft)	Crop Drying LPG (gal.)	Irrigation Diesel (gal.)	Irrigation Nat. gas (1000 ft)	Irrigation LPG (gal.)	Irrigation Elect. (KWH)	Total KCAL[a] (1000)
Dryland Crops										
Barley	7.7	15.8	6.1	1.3						624.623
Corn grain	12.0	31.2	13.6	2.6	7.5					1,361.587
Corn silage	23.0	16.1	12.1	2.2						1,442.901
Cotton	19.0	242.4	11.4	2.2						1,545.694
Legume hay	26.8	2.0	6.0	0.1						998.436
Nonlegume hay	20.6	0.7	8.5	1.5						1,140.615
Oats	6.9	30.0	6.0	1.2						616.113
Sorghum grain	10.2	28.4	6.1	1.4	0.6					794.501
Sorghum silage	16.6	13.0	6.4	1.5						1,018.502
Soybeans	11.5	26.5	5.3	0.2						497.213
Sugar beets	13.0	54.9	18.5	2.7						1,284.727
Wheat	7.7	19.3	5.0	1.1						590.620
Irrigated Crops										
Barley	12.2	10.7	5.9	1.3		0.1	0.0	0.1	4.0	809.925
Corn grain	11.5	93.6	10.3	2.5	8.0	0.4	0.0	1.0	43.4	1,562.612
Corn silage	19.2	47.0	8.7	2.1			0.0	0.0	0.0	1,318.353
Cotton	29.6	76.2	10.6	2.2		0.5	0.0	0.0	22.7	1,828.108
Legume hay	21.2	3.4	6.5	0.2		0.2	0.0	0.1	12.1	852.710
Nonlegume hay	12.8	0.1	6.4	1.4		0.1	0.0	0.3	12.0	898.631
Oats	13.7	25.0	5.4	1.2			0.0	0.0	0.0	844.599
Sorghum grain	14.4	22.5	6.3	1.4	0.1		0.0	0.0	0.0	925.931
Sorghum silage	18.3	11.6	6.5	1.5			0.0	0.0	0.0	1,077.002
Soybeans	9.5	21.9	1.3	0.1			0.0	0.0	0.0	393.381
Sugar beets	20.9	53.0	11.7	2.6		0.1	0.0	0.0	3.5	1,526.975
Wheat	13.8	11.7	4.5	1.0		0.2	0.0	0.0	9.7	827.799

[a] Total KCAL may not add up due to rounding errors. See Appendix F for conversion factors.

Table E.3. U.S. average per acre energy use coefficients by crops under the 10 percent energy cut (Model C) in 1985

Crop	Mach. Diesel (gal.)	Pest. KCAL (1000)	Fertilizer Elect. (KWH)	Fertilizer Nat. gas (1000 ft)	Crop Drying LPG (gal.)	Irrigation Diesel (gal.)	Irrigation Nat. gas (1000 ft)	Irrigation LPG (gal.)	Irrigation Elect. (KWH)	Total KCAL[a] (1000)
Dryland Crops										
Barley	7.8	11.6	6.8	1.4						687.188
Corn grain	12.8	27.7	13.6	2.6	8.0					1,417.743
Corn silage	23.3	15.9	13.1	2.4						1,521.168
Cotton	19.1	287.0	13.7	2.7						1,715.897
Legume hay	26.5	1.9	5.3	0.1						982.893
Nonlegume hay	20.8	0.6	8.8	1.5						1,166.759
Oats	7.7	14.4	6.2	1.2						630.516
Sorghum grain	11.7	19.3	6.3	1.4	0.6					851.214
Sorghum silage	16.4	13.1	6.5	1.5						1,024.583
Soybeans	12.3	23.8	5.2	0.2						520.703
Sugar beets	12.4	67.7	18.9	2.9						1,341.419
Wheat	8.9	9.5	4.7	1.0						609.249
Irrigated Crops										
Barley	11.5	19.4	6.2	1.4		1.5	0.5	2.3	224.6	1,674.039
Corn grain	13.5	72.6	10.7	2.6	7.9	0.7	0.1	1.3	98.2	1,809.736
Corn silage	17.8	40.5	10.1	2.4		1.0	1.2	2.1	260.7	2,444.583
Cotton	27.2	87.0	11.9	2.6		1.2	1.9	2.9	873.0	4,746.925
Legume hay	20.7	4.0	7.1	0.2		3.0	0.8	4.1	607.7	2,831.732
Nonlegume hay	12.8	0.1	6.6	1.5		1.5	0.0	0.2	69.5	1,119.437
Oats	14.5	19.4	5.3	1.2		0.4	0.0	0.6	277.0	1,648.917
Sorghum grain	14.0	23.7	6.5	1.4	0.1	1.3	2.1	3.1	466.7	2,854.542
Sorghum silage	17.9	15.0	6.5	1.5		3.9	0.3	4.2	306.1	2,224.363
Soybeans	12.0	16.9	1.5	0.1		5.3	3.3	8.6	209.3	2,316.577
Sugar beets	12.2	55.7	12.4	2.8		1.9	0.6	2.4	334.5	2,734.599
Wheat	13.7	9.7	4.5	1.0		1.4	0.4	0.7	257.0	1,639.800

[a]Total KCAL may not add up due to rounding errors. See Appendix F for conversion factors.

Table E.4. U.S. average per acre energy use coefficients by crops under high energy prices (Model D) in 1985

Crop	Mach. Diesel (gal.)	Pest. KCAL (1000)	Fertilizer Elect. (KWH)	Fertilizer Nat. gas (1000 ft)	Crop Drying LPG (gal.)	Irrigation Diesel (gal.)	Irrigation Nat. gas (1000 ft)	Irrigation LPG (gal.)	Irrigation Elect. (KWH)	Total KCAL[a] (1000)
Dryland Crops										
Barley	7.8	11.0	7.0	1.4						687.530
Corn grain	13.4	25.3	13.7	2.7	8.3					1,447.909
Corn silage	23.3	16.2	13.7	2.4						1,532.488
Cotton	19.1	305.1	13.6	2.7						1.750.247
Legume hay	26.2	1.8	5.5	0.1						976.720
Nonlegume hay	20.8	0.7	8.9	1.5						1,171.865
Oats	7.6	13.9	6.6	1.3						656.681
Sorghum grain	12.5	15.2	6.8	1.6	0.5					907.062
Sorghum silage	16.0	13.5	6.8	1.6						1,032.727
Soybeans	12.8	22.0	5.1	0.2						538.658
Sugar beets	12.4	69.2	18.1	2.8						1,308.866
Wheat	9.0	9.6	4.9	1.0						617.311
Irrigated Crops										
Barley	11.5	17.8	6.1	1.4		1.5	0.8	3.3	212.7	1,747.303
Corn grain	13.3	60.4	11.5	2.6	10.5	3.2	2.8	10.3	220.4	3,219.498
Corn silage	17.6	39.3	10.0	2.4		1.0	1.3	2.2	256.1	2,438.955
Cotton	24.8	87.8	12.1	2.7		1.3	2.3	3.4	702.0	4,341.253
Legume hay	20.7	4.2	7.1	0.2		2.9	0.8	3.9	645.2	2,940.581
Nonlegume hay	12.8	0.1	6.7	1.5		1.4	0.0	0.3	70.1	1,129.886
Oats	14.9	30.0	5.3	1.3		0.0	0.0	0.0	485.5	2,216.879
Sorghum grain	14.5	21.5	7.0	1.6	0.6	2.2	2.7	6.6	302.2	2,763.240
Sorghum silage	18.2	13.3	6.8	1.6		2.6	0.3	3.0	241.8	1,996.054
Soybeans	12.0	16.9	1.6	0.1		5.1	3.3	8.2	206.2	2,289.356
Sugar beets	20.6	52.4	11.9	2.7		2.7	0.9	4.2	328.2	2,858.159
Wheat	13.2	9.2	4.3	1.0		1.6	1.2	4.2	221.4	1,823.111

[a]Total KCAL may not add up rounding errors. See Appendix F for conversion factors.

Table E.5. U.S. average per acre energy use coefficients by crops under high exports (Model E) in 1985

Crop	Mach. Diesel (gal.)	Pest. KCAL (1000)	Fertilizer Elect. (KWH)	Fertilizer Nat. gas (1000 ft)	Crop Drying LPG (gal.)	Irrigation Diesel (gal.)	Irrigation Nat. gas (1000 ft)	Irrigation LPG (gal.)	Irrigation Elect. (KWH)	Total KCAL[a] (1000)
Dryland Crops										
Barley	7.8	12.2	7.9	1.7						761.422
Corn grain	13.8	24.4	20.4	4.1	9.0					1,898.828
Corn silage	23.4	15.9	17.9	3.5						1,830.317
Cotton	19.2	281.2	16.1	3.3						1,903.605
Legume hay	27.3	2.1	5.3	0.2						1,041.414
Nonlegume hay	21.2	0.6	11.2	2.1						1,350.118
Oats	7.5	16.9	8.9	1.8						793.856
Sorghum grain	12.5	15.3	12.3	2.9	0.7					1,291.519
Sorghum silage	15.8	13.7	8.2	1.9						1,110.050
Soybeans	12.7	22.4	6.2	0.3						557.450
Sugar beets	12.1	71.6	21.3	3.3						1,451.013
Wheat	9.1	10.1	8.0	1.7						820.997
Irrigated Crops										
Barley	11.6	16.2	7.2	1.7		1.4	0.9	3.2	229.1	1,874.616
Corn grain	12.7	73.7	17.6	4.1	7.7	5.3	1.9	8.7	168.4	3,204.210
Corn silage	17.8	32.3	13.7	3.4		2.7	3.2	4.3	256.3	3,370.475
Cotton	25.8	91.3	14.8	3.3		1.5	2.1	3.4	879.8	4,970.054
Legume hay	20.9	4.8	7.3	0.3		2.4	0.7	2.9	692.2	3,022.881
Nonlegume hay	12.9	0.1	9.0	2.1		1.4	0.0	0.2	68.6	1,286.517
Oats	13.6	29.7	7.7	1.8		0.5	0.1	0.7	398.6	2,120.357
Sorghum grain	14.1	22.1	12.6	2.9	1.0	5.3	2.9	8.9	252.7	3,216.696
Sorghum silage	17.1	15.9	7.9	1.9		8.7	0.6	9.2	229.6	2,448.277
Soybeans	10.5	19.7	2.1	0.2		4.0	4.9	8.9	264.5	2,822.330
Sugar beets	20.1	57.5	13.9	3.2		2.1	0.8	3.2	354.6	2,982.162
Wheat	12.6	14.8	7.5	1.7		1.7	1.4	4.0	389.4	2,523.969

[a] Total KCAL may not add up because of rounding errors. See Appendix F for conversion factors.

APPENDIX F: ENERGY CONVERSION TABLES

Table F.1. Energy conversion factors

	1 BTU	1 KCAL	1 Kg-meter	1 KWH	1 Barrel Crude Oil	1 Ft.-lb.
1 BTU	1	.252	107.514	2.93×10^{-4}	1.724×10^{-7}	777.65
1 KCAL	3.9683	1	426.649	1.622×10^{-3}	6.842×10^{-7}	3,085.96
1 Joule	9.4845×10^{-4}	2.3885×10^{-3}	.1019716	2.7777×10^{-7}	1.635×10^{-10}	.73756
1 KWH	3,409.52	859.184	367,098	1	5.878×10^{-4}	2,655,220
1 Barrel crude oil	5,800,000	1,461,600	6.2358×10^{8}	1,699.4	1	4.5104×10^{9}
1 Ft.-lb.	1.284×10^{-3}	3.241×10^{-4}	.13825	3.766×10^{-7}	2.2138×10^{-10}	1

Source: Cervinka et al. [3].

Table F.2. 1000 KCAL and 1000 BTU contained in one unit of energy source

Energy Source	Unit	1000 KCAL	1000 BTU
Gasoline	gallon	31.248	124.000
Diesel fuel	gallon	35.280	140.000
LP gas	gallon	23.814	94.500
Natural gas	1000 $feet^3$	269.010	1,067.500
Electricity[b]	KWH	2.661	10.560

[a]Source: Cervinka et al. [3].

[b]Electricity generating efficiency assumed to be 32.29 percent [10].

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